Eruption model of bromo volcano, east java, indonesia, in the 2011 eruption

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Bromo volcano is one of six volcanic cones inside the Sand Sea Caldera of Tengger volcanic complex. It is one of the most active volcanoes in Indonesia since four decades ago. The eruption gab time is between several months up to 16 years with duration in several days until several months. The eruption of 2011 was six years dormant after the phreatic eruption of June 8, 2004, and it took place about eight months as the longest period of eruption in historical time record. In this eruption period at least there were three times of new injected magma recognized as long as in one year before triggering the eruption. The first eruption occurred in late of November 2010 until the middle of December 2010 by mild phreatic eruptions and then followed by phreatomagmatic eruptions for the next step. The phreatomagmatic eruption ejected continually of the fine materials dominated and deposited in surrounding area up to 40 km from the crater, but the worst area that covered by thick ash deposit is only 10 km in radius with 50 cm thick. The eruption was reflected by mixture of lithic and juvenile fragments together in the ejected materials of the eruption as the fragmentation of magma due to contacted with ground water beneath. The eruption sequence was the main eruption step of 2011 Bromo eruption. A big eruption on February 5, 2011 is as the end of the phreatomagmatic eruption that was reflected by destroying of a lava plug. The fragments of lava plug of 50 cm in diameter were landed around 1,200 m from the crater. Due to damaging of lava plug in the conduit finally movement of magma from beneath is undisturbed and on February 8, 2011 was shown a fire sparkles like a big fire fox on the Bromo crater. It is the beginning of the strombolian eruptions until the end of the Bromo eruption in July 2011.

Drilling of a volcanic conduit beneath the Hiyoriyama Cryptodome, Kuttara Volcano, Hokkaido, Japan

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Hiyoriyama, located in Kuttara Volcano, Hokkaido, Japan, is a Quaternary dacitic cryptodome (350-550 m across, 130 m high), with active fumaroles at the summit. The cryptodome consists of augite-hypersthene dacite (SiO2: 70 wt. percent) that contains abundant mafic enclaves (SiO2: 57-59 wt. percent). Fission-track dating of the dacite suggests that the dome formed at 15 ka. In FY 2009-2010, a 350-m-long hole (the MIT-NB-5 hole) was drilled on a slanted trajectory passing beneath the centre of the cryptodome to study its feeder conduit. The drill rig was set at 200 m northeast of the dome, and the angle of the drilling was 41-50 degree from vertical. The drilling succeeded to penetrate the conduit zone at 300-310 m in drilled depth, and to recover boring cores between 18 and 350 m (core recovery 97 percent). The principal lithofacies of the MIT-NB-5 cores are pyroclastic deposits, coherent andesite and volcaniclastic veins (tuffisite veins). The pyroclastic deposits occur at 18-300 m and 310-350 m and comprise a succession of pumice flow deposits, pumice fall deposits, and base surge deposits. These pyroclastic deposits are inferred to have exploded from the Kuttara Volcano at 40 ka. The coherent andesite facies occurs at 300-310 m and has sharp contacts with the pyroclastic deposits. The andesite is massive, porphyritic, hydrothermaly altered and contains 57-62 wt. percent in SiO2. This facies is interpreted as a dyke intruded into the pyroclastic deposits. The dyke width, calculated from the core length (9.8 m) and drill-hole angle (41 degree), is 6.4 m. The volcaniclastic veins occur within the coherent andesite and in the pyroclastic deposits between 291 and 315 m. The total number of the veins is 30. The volcaniclastic veins are platy, zigzag or Y-shaped, up to 20 cm wide, and composed of subangular lithic and mineral fragments up to 2 cm across. They are hydrothermaly altered and commonly have pyrite-rich, alteration zones on either side of the veins. The volcaniclastic veins are inferred to have formed by injection of high-temperature fluid and entrained particles into temporally opening fractures. Despite the compositional contrast between the dome dacite (SiO2: 70 wt. percent) and the coherent andesite (SiO2: 57-62 wt. percent), we infer that the coherent andesite facies is the feeder conduit (dyke) of the dome, because (1) this facies is positioned just below the summit of the dome; (2) this facies and the adjacent pyroclastic deposits contains numerous volcaniclastic veins; and (3) this facies is almost identical in composition to the mafic enclaves (SiO2: 57-59 wt. percent) in the dome dacite. The compositional contrast between the dome (mainly dacite) and the feeder dyke (andesite) can be explained by magma ascent from a zoned magma chamber, consisting of upper dacitic magma and lower andesitic magma.

The fissure eruptions of Fuji Volcano, Japan, during the last 10,000 years

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Fuji Volcano, 3776m high, Central Japan, is the largest basaltic volcano in Japan, and located at the plate boundary between the North American Plate and Eurasian Plate. The magma plumbing system develops in the Philippine Sea Plate subducting beneath the above two plates. This paper discuss the effect of the stress field beneath Fuji volcano using eruptive fissures. The fissure eruption sites are good indicators to know the local stress filed in and beneath the volcano as well as the regional stress one. The local stress makes the feedback system on magma supply system in the shallow crust. The evolution of distribution on fissure eruption sites of Fuji Volcano suggests the restriction of eruption sites, that is, producing the more compressive condition around its own magma plumbing system. The fissure eruption sites younger than Cal BC 10,000 are easy to recognize on outcrops or using trenching survey. GSJ determined the ages of fissure eruption sites using trenching survey with 14C ages (Takada et al., 2007; Ishizuka et al., 2007; Nakano et al., 2007, Suzuki et al., 2007; Kobayashi et al, 2007). Fissure eruptions occurred at various azimuths during the period of Cal BC 10,000-6,000. The volcano became active again after a low activity period during the period of Cal BC 6,000-3,600 to construct the recent edifice with flank eruptions of various azimuths during the period of BC 3,600-1,500 (Yamamoto et al., 2005). The eruption sites became restricted to the summit to cause explosive eruptions during the period of Cal BC 1,500-300. The last summit explosive eruption was followed only by flank eruptions on the restricted flanks during the last 2,300 years. The dominant trend of the eruptive fissures is generally NW-SE, which is concordant to the axis of the regional maximum horizontal compressive stress filed. The eastern flank, however, caused a lot of fissure eruptions during the period of Cal BC 300-1100 (Yamamoto et al., 2011). In addition to the easter flank, the frequency of flank eruption became high on the NW and SE flanks during the Cal AD 700-1100 (Takada et al., 2007). After the effusive Jogan 864-866 eruption at the restricted vent, the eruptive fissures shifted its trend to NS during Cal AD 900-1100 (Yamamoto et al.,2005; Takada et al., 2007). The existence of high-level magma head is supported by high-level fissure eruption site up to 3,500 m-high just beneath the summit crater. Some of the fissure eruptions may have been caused by drain back. A decrease in explosively has relation to continuous degassing at the summit during AD 700-1200. The volcanic activity became low during Cal AD 1200-1700 before the last Hoei explosive eruption.

Numerical simulations of magma intrusion into crust near the surface by means of discrete element method

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We employed the software PFC2D (Particle Flow Code in 2 Dimensions) based on the discrete element method and attempted to simulate magma intrusion into crust near the surface. Although behaviors (e.g., initiation of a shallow magma chamber and formation of a sill) of the intruded magma depend on various factors, here we paid attention to the intrusion magma velocity, which reflects overpressure conditions.

In discrete element modeling, all materials are approximated as assemblies of many particles, and each particle is connected by two elastic springs (having normal and shear stiffness). In addition, "contact bond" parameters for determining the strength of material (rock) must be set between all adjacent particles. By trial and error, these parameters are determined by biaxial test in a computer. A Young modulus of 16 GPa and a Poisson ratio of 0.21, as elastic constants of the surface crust, and viscosities in range of 10^7 - 10^{10} Pa s, for middle-high viscous magma, were assumed in this study. The normal and shear contact bonds for intruded magma were not set in order to maintain fluidity.

Before applying the above-mentioned magma model to simulations of magma intrusion into the crust, extrusions to the surface of these magma were simulated in order to confirm whether the magma model behaves realistically. As a result, it was shown that the shape of extruded magma (lava) depends on the viscosity of the magma and its flow velocity in the conduit. The high viscous magma makes a lava dome at the surface and its interior structure is distorted concentric circle patterns. These structures due to the high viscous magma have been simulated by some analogue experiments. From these pre-simulation results, it was concluded that the developed magma model was suitable for simulations of magma intrusion.

As a preliminary simulation model for magma intrusion, we modeled the surface crust by a rectangle of width and depth 5 and 1.6 km, respectively. The radius and density of the particles constituting the model crust were assumed to be 4.8 - 6.4 m and 2500 kg/m^3, respectively. The radius and density of the particles constituting the model magma were assumed to be 0.8 - 0.96 m and 2200 kg/m^3, respectively, and a probable intrusion velocity was given to the particles. The volume of the intruded magma was set to 2 10^5 m^3 in all simulations. As a result, it was found that the shape of the intruded magma was circular at an initial stage of intrusion, and that this initial shape did not depend on the intrusion velocity. However, the subsequent change in the shape over time did depend on the velocity. A low velocity made the intruded magma become elliptical, elongating upward and deforming the surface greatly over a wide area. In contrast, a high velocity made the magma intrude into a circular shape, the lower parts of which elongated sideways, or in a rounded triangular shape.

Stress and strain distribution in the shallow crust during dyke and sill emplacement

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The mechanics of sill formation are important for understanding magma distribution within the shallow crust and the tendency for these magmas to intrude or erupt. We present a series of layered gelatine analogue experiments monitored with a Particle Image Velocimetry (PIV) system to document the small-scale deformation processes in the host material during dyke and sill emplacement. Experiments are prepared comprising multiple layers, with small strength contrasts (comparable to those between crustal strata) created by varying the gelatine concentration and allowing sufficient time for it to reach its Young's modulus plateau. Injection of dyed water (the magma analogue) into the solid gelatine from below causes a vertically propagating penny-shaped experimental dyke to form. A horizontal sill then forms along a weak contact beneath a more rigid layer. To monitor displacements within the gelatine using the PIV technique, neutrally buoyant fluorescing particles are added to the gelatine during experiment preparation. Two high-speed cameras are positioned outside the tank in a plane perpendicular to the strike of the experimental feeder dyke, and parallel to a vertical high-power laser sheet that fluoresces the particles in the gelatine with short intense pulses. The cameras and laser sheet are triggered so that images are recorded at known time intervals. Incremental displacement vectors are calculated by cross-correlation between successive images. Spatial derivatives of the velocity field yield map the gelatine's 2-D strain components within the laser sheet. As the gelatine deforms elastically, the calculated strain correlates with the stress distribution. PIV provides new insights into the dynamics of sill formation by allowing small-scale stress and strain perturbations within the host gelatine layers to be measured for the first time at the time of sill inception. These experiments highlight the stress and strain partitioning that occurs between layers of contrasting elastic properties during intrusion, and the important role this plays in sill initiation.

Energy sources, behaviour, and durations of volcanic eruptions

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Why are some eruptions of long duration and others of very short duration? Why do some eruptions of short duration produce much more eruptive materials than other eruptions of much longer duration? Why do most volumetric flow rates (effusive rates in the case of lava production) decline rapidly after the peak, whereas some decline much more slowly? These are all fundamental questions in theoretical and applied volcanology that need to be answered in order to forecast the likely behaviour and duration of an eruption once it has started.

Thermodynamically, all volcanoes are open systems; they exchange heat and materials with their surroundings. For an eruption to occur, there must be sufficient energy within the volcano to propagate a feeder dyke to the surface. Furthermore, for a significant volume of magma to be issued during an eruption, there must be energy available to press the magma out of the chamber and to the surface. Here we provide energy models to explain (1) the duration of eruptions, as well as their (2) volumetric flow rates, (3) behaviour, and (4) the eruptive-volume size distributions. We show that the primary energy responsible for feeder-dyke formation is elastic energy, which consists of two parts: (1) the strain energy stored in the volcano before magma-chamber rupture and (2) the work done through displacement of the flanks of the volcano and the expansion/shrinkage of the magma chamber itself. Large volumetric flow rates are related to the size of the aperture of volcanic fissure, the magmatic overpressure, and the work done through the displacement of the flanks of the volcano.

In the absence of a collapse caldera formation, the duration of an eruption (from a chamber of a given size) is primarily related to the chamber excess pressure, which can be maintained for a considerable time (giving rise to eruptions of long duration) depending on several factors. These factors include (1) flow of new magma (from a deeper reservoir) into the shallow chamber during the eruption; (2) gas exsolution and expansion in the chamber during the eruption; and (3) shrinkage (volume reduction) of the chamber during the eruption.

Normally, the rate of inflow of new magma into a shallow chamber is too low to have significant effects on the duration of the eruption. Gas exsolution and expansion is certainly one of the fundamental factors for determining the duration and volumetric flow rate of eruptions issuing evolved magmas, but is much less so for primitive magmas. Elastic, and inelastic, shrinkage of the magma chamber is a major factor contributing to the duration and volumetric flow rate of an eruption. The rate and size of shrinkage depends on the strain energy stored in the volcano before the eruption. We show that stratovolcanoes generally store more elastic energy, per unit rock volume, than basaltic edifices, a fact that partly explains their commonly widely different behaviour during eruptions.

Structural variation of the feeder dikes of explosive eruptions in Miyakejima, Japan

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Basaltic eruptions exhibit wide variation about its explosivity, from stable lava effusion, mild-violent strombolian eruption, to plinian eruption. Complex behavior of magma during flow within the conduit may one of the controls of the style of the eruption activities, and the structure of the conduit may also control the behavior of the ascending magma through the conduit.

We describe various type of the cross section of vent, from feeder dike to its surface products, in the caldera wall of Miyakejima, Japan. Many basaltic dikes fed fissure eruptions in Miyakejima during the last 10,000 years. The AD 2000 caldera truncated a basaltic stratovolcano with numerous feeder and non-feeder dikes. The depth of diatreme and the horizontal size of its pyroclastic cone represent the difference of explosivity. Some feeder dikes connect directly to the lava flow without any pyroclastic cone, indicating the effusive eruption. Some feeder dikes connect to pyroclastic deposit, indicating pyroclastic eruption. Some feeder dikes connect to the base of small and conical scoria cone, with 100- 200 meters across and several tens meters high. Size and internal structure of the scoria cone indicates the mild strombolian activity. Uppermost ten meters of these feeder dikes shows upward-flaring (widen the dike thickness to the surface), which infers the magmatic erosion of the dike wall by explosive activities within the conduit. More explosive activities formed some diatremes. The depth of these diatreme reaches 100 meters from the original ground surface. Typically, these diatremes connect to very-flat scoria cone and wide-spread thick scoria-fall deposit, which indicates the highly explosive activities. The sizes of these flat scoria cones are comparable to that of the scoria cones which was built by sub-plinian eruption (e.g., Izu-Oshima 1986). Upward flaring structure of the diatreme indicates the effective mechanical erosion of the dike wall by the explosive activities. The wider feeder dikes for lager diatreme suggests the higher magmatic overpressure for the explosive activities in comparison to the less-explosive feeder dikes. Comparison of the structures of these feeder dikes indicates that the variation of the depth of fragmentation (or explosion) controls the explosivity of the basaltic eruption. The fragmentation depth of mild strombolian feeders are relatively shallow (<10 m), whereas the deep rooted diatreme of the sub-plinian feeders indicates the deep fragmentation more than 100 meters from the original ground surface. The structural variation of feeder dikes suggests that the differences of magmatic overpressure and the fragmentation depth may control the eruption behavior.

Physical characteristics of kimberlite and basaltic intraplate volcanism, and implications of a biased kimberlite record

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Kimberlite volcanoes are rarely preserved in the geological record and much of what we understand about the eruption of kimberlite magmas has been deduced from studies of sub-volcanic structures and deposits. This presents us with problems because the surface products that are commonly used to infer eruptive processes at other volcanoes have been removed. We have investigated bias in the record of kimberlite volcanism by using newly acquired size data on over 900 kimberlite bodies from 12 kimberlite fields eroded to depths estimated to be between 0 m to 1200 m, and by a cautious comparison with intraplate monogenetic basaltic volcanic fields. Eroded kimberlite fields are composed of pipes, or diatremes, and dikes and within any one kimberlite field, regardless of erosion level, kimberlite bodies vary in area at the Earth's surface over 2 to 3 orders of magnitude. Typically 60 to 70 percent of the bodies are less than 10 percent of the area of the largest body in the field. The data indicate that the selective removal of surface volcanic structures and deposits by erosion may have distorted the geological record of kimberlite volcanism. Selective mining of preferentially large, diamondiferous kimberlite pipes and underreporting of small kimberlite pipes and dikes adds further bias. A comparison of kimberlite volcanic fields with intraplate monogenetic basaltic volcanic fields indicates that both types of volcanism overlap in terms of field size, volcano number and size, and typical erupted volumes. Eroded monogenetic basaltic fields comprise dikes that fed effusive and weakly explosive surface eruptions, and diatremes generated during phreatomagmatic eruptions, and are structurally similar to eroded kimberlite fields. Published data suggests that kimberlite magmas can erupt in a variety of ways and that most data, gathered from the largest kimberlite pipes, may not be representative of kimberlite volcanism as a whole.

Fragments within fragments: are composite bombs hints of weakness or sustained violence?

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Bombs and lapilli containing or consisting of smaller fragments are composite clasts, and are produced in many mafic eruptions. They have been attributed to accretion of highly fluid pyroclasts in gas suspensions of either conduits or plumes, to hot-state vent/conduit recycling of pyroclasts, and depositional amalgamation. It is important to distinguish composite clasts formed within sustained eruption columns from the others because the hazard and depositional footprint of the former is much larger. Bombs in some inferred gas-rich systems are argued to grow by particle collisions under thermal conditions that allow surface-tension reshaping, requiring assembly of bombs while immersed in a gas jet. The jet is also considered to elutriate, rather than accrete, fine ash. Suspension of a 20 cm bomb in gas-rich particle-poor conduit flow or in gas-thrust regions of plumes requires sustained velocities associated with "violent Strombolian" eruptions that blanket many tens of square kilometres with decimetres-thick deposits. Basaltic to nephelenitic bombs formed by discrete explosions in conduits characteristicstically contain wallrock fragments. The explosions fragment fluid magma and wallrock but are ineffective in clearing the material from the conduit or vent. This general mechanism requires discrete explosions, and implies limited particle dispersal. Composite fragments from maar-diatreme environments of nephelenitic to basaltic tholeiitic compositions are typically country-rock rich and display a variety of textures, surface features, and styles of assembly. Bombs at Rotomahana incorporated many fragments that show minimal thermal alteration and must have been assembled and cooled over short timescales. Associated with fragmentation zones in Hopi Buttes maar-diatremes, are composite bombs and a variety of clastogenic lithic-rich coherent rocks, whereas in the Karoo province such composite clasts accompany lithic-rich lava flows. Composite fragments in the Antaractic Ferrar province are present in pyroclastic flow deposits of substantial extent, but also with locally dispersed layers; plume-fed fall deposits are not significant. The most consistent feature of reported composite clasts is their occurrence in mafic-intermediate to ultramafic cones or maar/diatremes, and not associated with dispersed fall deposits. The range of magma types and volcanic environments with composite bombs argues against an origin dependent on unusually fluid magmas or extreme eruption conditions. Weak dispersal of fragments formed in discrete explosions allows fallback and amalgamation or re-incorporation into magma of first-generation fragments, re-ejected by subsequent explosions as lapilli or bombs. Where fragmentation also produces wallrock fragments, these are incorporated into the composite fragments.

Linking maar eruptions with diatremes: experimental insights from single and multiple buried explosions

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Maar-diatreme eruptions are hazardous to people and infrastructure; kimberlitic diatremes can also contain diamonds so they are economically important. Yet processes occurring in the subsurface diatreme and their relation to surface eruptions are not yet well understood. Previous laboratory studies have addressed different types of potential 'diatreme-forming' processes, whereas previous field-scale experimental studies have addressed cratering but without significant focus on sub-crater deposits, and only for single explosions. We conducted field-scale experiments at the Geohazards Field Station (University at Buffalo, NY) using single and multiple buried chemical explosions in a prepared, layered granular substrate. The explosions produced craters, extra-crater deposits and sub-crater deposits analogous to volcanic maar craters, tephra rings and incipient diatremes.

We excavated a series of vertical cross-sections through the deposits after the explosions. This revealed a significant zone of sub-crater deposits, extending several decimeters below the post-shot craters. Videos of the experiments show vertical ejection and fallback of material, especially for the explosions that occurred below optimal depth of burial. In other words, the majority of the material which formed these eruptive plumes fell back directly into the transient explosion craters. The sub-crater deposits have an upper zone containing domains sourced from different substrate depths, and an underlying zone distinguished primarily by being more loosely packed than the original substrate. We infer that much of the loosely packed material was disassembled, vertically transported to different heights during the explosions, then fell back without significant relative lateral movement of grains. One explosion ejected material from the deepest substrate horizon, but it was redeposited only within the crater and is unrepresented in the ejecta ring.

Implications of the experiments for maar-diatreme volcanoes are as follows: (1) vertical focusing of deep explosions in the diatreme explains the deficit of deep wallrock lithics observed at maar volcanoes; (2) direct vertical fallback is possibly a major process forming diatreme deposits; (3) direct fallback from numerous explosions at various depths and lateral positions would eventually produce a diatreme fill that looks "well mixed" overall; (4) even in our limited simulation the number and scaled depth of explosions clearly affect diatreme size and structure. While representing a pilot study, these initial results already advance our understanding of explosive cratering and have implications for understanding how some features of maar-diatreme volcanoes and some kimberlite pipes form.

Volcanic jets, plumes and collapsing fountains: evidence from large-scale experiments, with particular emphasis on the entrainment rate.

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The source conditions of volcanic plumes and collapsing fountains are investigated by means of large-scale experiments. On experiments, gas-particle jets issuing from a cylindrical conduit are forced into the atmosphere by a variable mass flow rate. Dense jets (high particle volumetric concentration) generate collapsing fountains whose height scales with the squared exit velocity. This is consistent with Bernoulli's equation and means that kinetic energy is transformed into potential energy without loss against friction with the atmosphere. The dense collapsing fountain, on hitting the ground, generates an intense shear flow similar to pyroclastic density currents. Dilute hot jets (low particle volumetric concentration) reach a height much smaller than that resulting from Bernoulli's equation, meaning that part of the kinetic energy is lost through friction with the atmosphere. This causes a significant air entrainment and dilution, which leads to the formation of a buoyant column (plume) resulting in particles settling from its margin, similar to pyroclastic fallout. By means of the functional relationship between the initial densiometric Froude number and normalized height, the scaling of experiments is compared with data of the recent fluid-dynamics literature.

In order to assess the different entrainment rate between collapsing fountains and plumes, experiments were investigated by quantitative video analysis. Results show that dense collapsing fountains are formed only when air entrainment is not significant. Cold dilute experiments result in an entrainment coefficient of about 0.06, which is typical of pure jets in fluid-dynamics. Hot dilute runs result in an entrainment coefficient of about 0.11, which is typical of plumes.

An initial densiometric Froude number of 3 sets the limit between dense collapsing fountains and dilute jets-plumes. We use this value for obtaining a diagram of the stability fields of pyroclastic density currents and pyroclastic fallout.

Insights on a new pattern of dyke propagation in volcanic edifices

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Dyke intrusions in volcanoes contribute to edifice internal growth and feed flank and summit eruptions. Understanding the control factors on dyke paths is thus critical to assess areas prone to vent formation, and for the general understanding of how volcanoes work.

As a contribute to this wide topic, we present our field and laboratory results dealing with an understudied magma path system, characterized by a central summit rectilinear volcanic rift zone that turns into an outward-widening, fan-arranged pattern of eruptive fissures and dykes at two opposite volcano flanks, giving an overall “hourglass” configuration.

We identified nine elongated volcanoes in different tectonic settings showing evidence of this pattern, and we analysed their geological, structural and morphometric characteristics, highlighting those volcanic-structural features that depict this configuration.

Then, in order to constrain the relation between the state of stress in the edifice and dyke propagation, we developed a series of scaled analogue models. Volcanic edifices were reproduced in gelatine with defined geometries based on field data, while sheet intrusions were simulated by injecting coloured water at different locations below the volcano respect to its flanks and elongation axis.

Our results suggest that this “hourglass” configuration of magma paths in volcanoes can result from the dominance of stress tensors with different geometries in diverse parts of the edifice. These stresses should also have diverse origins; while regional tectonics might exert a control on the orientation of the central part of the rift system, the geometry of the edifice (with defined ranges of elongation and volume) can reorient the local stress field and dictate the pattern of dyke propagation at the volcano edges. These findings complete and integrate previous works on the development of volcanic rift zones, contributing to the assessment of volcanic hazards associated to the opening of dyke-fed eruptive fissures on the volcano flanks.

The tertiary volcanic sub-marine formation of kuta-beach, lombok, indonesia, a geological and educational site of high patrimonial value

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At the South of Lombok Island, Indonesia, the morphology of the coast corresponds to a succesion of indented bays interupted by eroded Tertiary volcanic remnants. The distribution of the old volcanic cones that underwent hydrothermal alterations corresponds to the presence of feeder dikes of basltic andesite lava oriented ESE. This Late Oligocene to Early Miocene submarine volcanic deposit is constituted by volcanic breccias, tuffs and basaltic andesites lavas, with intercalations of marine deposits lenses of Oligo to Miocene limestones. A large bloc of hyaloclastite displaying radial cracks linked to a contraction during the process of cooling. Numerous cavities due to the gas trapping during the sudden cooling. On large surfaces of the abrasion platform, a loose network of perpendicular cracks underlined by recristallisation due to fluid movements, attests the importance of contaction during cooling. The result of auto-brecciation of basaltic lava flow can be observed locally as well as pyroclastic flows constituted of oriented hyaloclastite-peperite fragments displaying a reverse grading. A submarine volcanic edifice can hardly be found onshore in the Indonesian archipelago. Identification of the morphological features and study of the characteristic of products resulting of sub-aqueous volcanic activities will allow to better understand the eruptive mechanisms. A good exposure of dikes, fragmented sub-marine lava flows, hyaloclastite and peperitic deposits, supported by a rare and beautiful beach composed exclusively by foraminifera fossils-sands of Schlumbergerella floresiana contribute to confer to this geological and educational site a high patrimonial value.

Key words : Kuta beach Lombok, Submarine Tertiary volcanism, hyaloclastites, peperites

Finite element analysis of conduit wall rock stresses associated with steady flow models

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Conduit erosion (i.e. the permanent removal of wall-rock) modifies conduit geometry during eruptions and affects eruption dynamics. However, there has been very little modelling of conduit wall-rock failure and none coupling erosion and fluid dynamic models.

Finite element analysis is a powerful tool to elucidate the behaviour of the wall-rock during both dynamic and static loading and is capable of dealing with inherently non-linear and complex systems. Initial investigations using the FEA package Abaqus have focused on conduit wall-rock loading based on the pressure profiles determined by the steady 1-D explosive eruption dynamics models of Costa et al., 2009. Their models assume a 6000 m conduit linking the chamber (of variable pressure) to the vent with a cylindrical, dyke-like or hybrid (dike that transitions to a cylinder) geometry. The fluid pressures in their set of simulations range from +30MPa to -106MPa, with respect to lithostatic.

FE models loading the conduit walls with the stress from the simulated fluid pressures suggest significant wall-rock failure would occur for all geometries modelled. For example, the pressure profile for a cylindrical conduit in an elastic medium (Youngs modulus = 40 GPa, Poissons ratio = 0.25, and yield strength = 20 MPa) results in damaged volumes of 10^7 m^3. Damage is focused around, and particularly important in, areas of conduit underpressures, as this material will implode into the conduit; erosion of damaged overpressured areas requires a further mechanism to remove material (e.g. magmatic shear stress or particle collisions). The forecasted yielded volumes exceed that of the conduit by an order of magnitude, suggesting that significant wall-rock failure would inhibit the development of the modelled steady flow pressure profiles. FE analyses with a dyke-like geometry suggest that significant failure would be focused near the dyke tips. Results for a dyke underpressure of 50 MPa (properties as above) indicate yielded cross-sectional areas of hundreds of square meters. Due to the spatial relationship between this damaged material and the dyke, this material would not easily be removed, although increased permeability through damage could be important in promoting magma-water interaction.

The amount of damaged material strongly depends on the initial size of the conduit and the assumed rock rheology. For increasingly complicated, quasi-steady models coupling 1-D flow and evolving conduit geometry based on FE wall-rock failure, an elastic-plastic wall-rock rheology may be more appropriate. In the static loading done to date, adjusting the rheology from elastic to elastic-plastic increases the damaged volume by orders of magnitude.

From dike to plug: critical physical transitions in the evolution of sustainable basaltic volcanism

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Basaltic volcanic eruptions commonly are characterized by three stages. In the upper few kilometers of the crust, magma rises in planar dikes, resulting in fissure eruptions when they intersect the surface. In some cases, the fissures may not feed significant eruptions and may quickly (within hours) die out. In other cases, magma continues to erupt and localizes into discrete vents, until the flow is sustained through a central vent, which is able to carry much greater volumes of magma to the surface. These types of eruptions have been well documented in places like Kilauea volcano in Hawaii and are inferred to have operated in ancient systems like Ship Rock, New Mexico. However, the physical processes governing the evolution of conduit geometry from dike-like to plug-like and the associated eruptive dynamics are poorly understood. Field evidence from Ship Rock provides insights we use to develop a framework for what processes may have caused the evolution of dikes into plugs. Ship Rock is a maar-type diatreme standing 600 m above the surrounding land surface, with minette dikes extending radially away. Systematic joint sets in the host rock (Mancos shale) adjacent to dike contacts and the presence of breccias along the margins of the dikes and around plugs suggests that brittle deformation and subsequent erosion of the host rock was primarily responsible for changing conduit geometry. Fracture orientations and petrographic analysis of the breccias have allowed us to construct a conceptual model for what style of deformation has taken place, the sequence of these deformational events, and the stress state that gave rise to this deformation. We hypothesize the following order of events: 1) dike-parallel fractures form in the host rock ahead of the propagating crack tip; 2) magma intrudes and solidifies at the contact and oxides and calcite fill in pore space in the adjacent host rock; 3) dike-perpendicular fractures form in the host rock; 4) solidified magma fractures and host rock partially fluidizes; 5) fractured magma is eroded by the flow of molten magma; 6) fractured host rock is eroded by the flow of molten magma. An analysis of the state of stress around a dike identifies the primary controls on the various styles of deformation. The stress state includes mechanical stresses from dike opening, thermoelastic stresses from heat transfer, and pore pressure increases from coupled heat transfer and groundwater flow. We present the field evidence for the conceptual model and preliminary results from the stress analysis. Ultimately, physics-based numerical models will be developed to test which physical mechanisms primarily control the evolution of fissure- to central- type eruptions, and under what conditions this transition is likely to take place.

Structure of phreatomagmatic crater rows from gravity surveying. Conduit shape comparisons between the fissures of the 871 AD Vatnaoldur and 1477 AD Veidivotn eruptions, south central Iceland

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The 60 km long Vatnaoldur and Veidivotn volcanic fissures in south central Iceland belong to the same SW-NE trending fissure swarm that is part of the Bardarbunga volcanic system. Eruptions on the fissure swarm have in postglacial times been both effusive, producing large lava fields, and explosive, producing the largest known basaltic tephra layers in Iceland. Ground water level is high within the southwestern part of the fissure swarm and a large river flows through the volcanic area.

The two most recent eruptions on the southwestern part of the fissure swarm occurred in 871 $\pm$2 AD when the crater row of Vatnaoldur was formed, and in 1477 AD, when the Veidivotn fissure was active. Both eruptions produced basaltic tephra layers of several cubic kilometres. Minor effusive phase at the end of the Veidivotn eruption, filled the bottom of the large phreatomagmatic craters from the main phase, while only tephra was produced in the earlier Vatnaoldur eruption.

The aim of the project is to model the structure of some volcanic conduits from both fissures, in order to figure out their filling materials and understand better their process of formation. A large density contrast is to be expected between the crater rims made of tephra (density 1200-1900 kg/m3) and the lavas that fill the Veidivotn craters (2300-2700 kg/m3). Therefore the gravity method was chosen to figure out the volcanic structures.

Six profiles were surveyed across six explosive craters using a LaCoste Romberg gravity meter and kinematic GPS. Complete Bouguer anomalies were obtained by integrating the gravitational effects of the mass of the topography using a high resolution DEM. Two profiles cross the Veidivotn fissure whereas the other four cross Vatnaoldur. Preliminary results do not indicate gravity anomalies associated with the conduit of the fully phreatomagmatic Vatnaoldur crater row, suggesting that the crater fill has the same density as the surrounding bedrock of tephra, hyaloclastite and lava. In contrast, the lava-filled craters of Veidivotn show up as gravity highs. Forward models of the craters indicate the existence of a few hundred meters wide and >100 m deep lava fill in the phreatomagmatic Veidivotn craters. The results therefore indicate considerable excavation of the pre-existing uppermost part of the bedrock in these powerful phreatomagmatic eruptions.

Eruption of crystal-rich basalts following a large sector collapse: Evidence from IODP cores sampled offshore Montserrat

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Recently sampled IODP leg 340 cores sampled offshore Montserrat in the Lesser Antilles have recovered a large amount of marine sediment, which is intercalated with tephra fallout deposits, reworked volcaniclastic and bioclastic turbidites sequences resulting from large landslides. This information will provide a wealth of information about the mechanisms of these volcanic island landslides as well as the evolution of the style and composition of the volcanoes through time. In recent years we have discovered more about Montserrat's geomorphological, chemical and eruptive history through information gained from shallow marine cores, subaerial work and now deep IODP cores. Montserrat comprises 4 volcanic centres dating back to 2.6 Ma, including the presently active, Soufrière Hills volcano. As with most subduction zone volcanoes, the majority of the volcanoes on Montserrat erupt andesite, which has ideal density and viscosity qualities which facilitate ascension and eruption of this intermediate composition. The presence of a basaltic volcanic centre at Montserrat at 130 ka (South Soufrière Hills) is therefore puzzling. However new data from the IODP cores find thick basaltic (46% SiO_2) fallout units, which overly one of the largest sector collapses discovered offshore Montserrat (8 km^3). This basaltic unit is crystal-rich and contains normally zoned phenocrysts of plagioclase, olivine and two-pyroxene. This study uses geochemical, textural and petrological work to explore whether this represents an unloading and decompression event, which led to the eruption of these dense and crystal-rich basaltic magmas.

Evolution of the phreatomagmatic Cova de Paul eruption, Santo Antao, Cape Verde Islands: links between the development of the eruption and the growth of the crater.

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Episodes of hazardous phreatomagmatic explosive activity that excavate large deep craters occur within otherwise less dangerous effusive to mildly explosive magmatic eruptions at high-elevation vents on many oceanic island volcanoes. The water driving these explosions is sourced from freshwater aquifers within the volcanic edifices, whose location and other characteristics will influence crater growth and final geometry. Here we describe crater wall sequences and near-vent deposits around the large Cova de Paul crater on the island of Santo Antao, Cape Verde Islands, which provide some insights into a transition from mild magmatic to violently explosive phreatomagmatic activity in one such eruption. This pre-historic but well-preserved crater formed in a single eruption that produced extensive low-temperature, lithic-rich phreatomagmatic ignimbrites and surge deposits; these are interbedded in proximal outcrops with airfall to mixed fall and flow breccia and ash beds containing varying proportions of lithic and juvenile clasts, pointing to a series of climactic explosions within an extended period of milder phreatomagmatic explosive activity.

Prior to the transition to phreatomagmatic activity, the eruption had been characterized by mild Strombolian activity that produced scoria and spatter deposits of broadly tephritic composition. The upper parts of the Strombolian sequence contains distinctive flow-banded angular sub-glassy juvenile clasts, compositionally identical to the Strombolian scorias, that become larger and more abundant just below the transition to phreatomagmatic activity. We interpret these as fragments of flow-banded chilled margins from the walls of the eruptive conduit. Thermal shattering of these margins to produce the angular sub-glassy clasts may have allowed increased groundwater flows into the conduit, attainment of a critical coolant input ratio, and the onset of the phreatomagmatic explosions. The lack of angular sub-glassy clasts in the rest of the eruptive sequence suggests that the chilled margins never re-established and that subsequent variations in the intensity of phreatomagmatic activity were controlled by water flow to the conduit as the crater was excavated to deeper levels and different aquifers were tapped and depleted. We find that whereas most of the lithic clasts in the mixed units can be matched with rock units in the exposed crater walls, implying widening of the crater during periods of low-level explosivity, the ignimbrite and surge units contain hydrothermally altered clasts that appear to have originated from deeper in the volcanic edifice implying that during these climactic episodes the crater vent walls were being actively excavated to as much as several hundred metres below the surface of the volcano.

Dolerite sill body inferred from bore hole investigation in the Yufutsu Oil and Gas Field, Hokkaido, North Japan

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Petrographic study of the dolerite intrusions in the Yufutsu well, drilled over 5 km depth revealed that the dolerite multiple sills up to 1 km in total thickness intruded into the Mid Eocene coal-bearing Formations of the Ishikari Group and the Late Eocene fine-grained marine strata of the Poronai Formation. The thickness of each sill ranges from several m to over 30 m. The dolerite rocks are characterized by variable textures ranging from typical coarse-grained dolerite texture to porphyritic texture with fine-grained crystal and /or glassy groundmass. Plagioclase size distribution indicates small and needle form at the levels of the Poronai Formation and bottom of the Ishikari Group, and large and square form at the middle of the Ishikari Group. The dolerite rocks have basaltic andesite to andesite compositions (54-59 SiO_2 wt percentage). Main mineral assemblages of the dolerite rocks are divided into plagioclase (SiO_2 rich rocks) and plagioclase + clinopyroxene (SiO_2 poor rocks). Upper most and bottom part of sills consist of mafic rocks, middle part of sills repeated layers of felsic and mafic rocks. These features suggest that the multiple sills body may indicate marginal facies of the cross section of magma chamber characterized by layering in gabbro plutons.

Among the igneous rocks in the Yufutsu Oil and Gas Field, a subset of the Oligocene volcanic rocks in the Minami-Naganuma Formation underlain by the Late Eocene Poronai Formation is distinctive on the basis of markedly high incompatible element abundances. The dolerite rocks also show an enrichment in incompatible elements. The similarity of geochemical signature in the Oligocene volcanic rocks and the dolerite sills suggests that the former exhibits effusive facies and the latter has played the role of parent magma chamber emplacing in the Poronai Formation and the Ishikari Group.

2012 Copahue volcano eruption (Argentina)

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Copahue volcano (37,8°S, 71,2°W, 2997 masl) is one of the major examples of active volcanism in Argentina. This basaltic-andesitic stratovolcano is located on the western edge of the Caviahue caldera in the Andes. The volcano summit has nine craters aligned in the N60 °E direction, the eastern crater is the active one and it currently hosts an acidic crater lake (pH ∼1) with a diameter close to 250 m and 40 m depth. During the last 250 years this volcano has experienced at least 12 low intensity phreatic and phreatomagmatic eruptions. The last eruptive cycles took place from the active crater, during 1992 and 1995 characterized by phreatic eruptions and from July to October 2000 with a phreatomagmatic eruptive type, all of them with VEI 1-2. After the 02-27-2010 Maule earthquake (Chile, Mw 8.8), several variations were observed related to the local seismicity, primarily associated with an increase in the amount and type of signals Later, on 12-01-2011 a seismic swarm was registered and gaseous emissions from the crater lake started to increase in both temperature (62 °) and acidity (pH<0). Deformation measurements were made by processing Envisat images available from January 2011 until April 2012 allowing the construction of 33 interferograms. The analysis of temporal deformation series indicate an inflation process starting on November-December 2011, located mostly on the northern slope of the volcano edifice. After April 2012 the satellite was out of operation.The 07/16/2012, after a marked increase in seismic activity from 07/09/2012, some phreatic events were observed and two days later a phreatic explosion throws pyroclastic sulfur from deposits of the crater lake bottom. The phreatic manifestations produced by degassing continued until December 2012, decreasing the volume of water from the crater lake. Finally, on 12-22-2012 at 9:15 pm a phreatic eruption began, vaporizing the crater lake waters and the hydrothermal system in a few minutes. At 9:40 hs it became phreatomagmatic with generation of a convective cloud and emission of blocks and bombs in ballistic projection outflow of the plume. Diluted pyroclastic flows were observed during this eruptive phase. Several hours later (15:30 hs) burning clouds were viewed getting out of the crater produced by combustion of volcanic gases. Thus, an eruptive strombolian phase began, with the emission of elongated volcanic bombs, up to 1.5 m in length. This eruption ended in a few hours, continuing to the present with gas emissions.

Petrographic characterization of material ejected during eruptive phases of Copahue volcano (Argentina) in 2012

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Copahue volcano is an Andean active basaltic-andesitic stratovolcano. The crater currently hosts an hot and acidic crater lake. On July 19, 2012 a phreatic explosion occurred with emission of pyroclastic material, producing a small plume that extended 18 km on ESE direction. A sample of this event, recovered from the crater, was constituted mainly by sulphur pyroclasts, with low proportion of pumice and scoriae fragments, irregular argillaceous white material and accidental/accessory fragments. Sulphur pyroclastic material have variable sizes (3-4 mm), mostly globular morphology with vesicles, like perfect spheres or elongated forms in some cases, and like deformed 'drops' in others. On December 22, 2012 a new magmatic pulse initiated with a rapid vaporization of the Crater Lake and a phreatic eruption. Minutes later it became in phreatomagmatic with convective cloud generation and ballistic emission of blocks and bombs, and pyroclastic fall of ash, mainly dark brown pumice fragments, from the plume. Several hours later the eruptive phase turned to strombolian style, with emission of elongated volcanic bombs. The emitted material sampled 9 km far from the volcano corresponds to lapilli-sized tephra. It is mainly composed by irregularly to subrounded shaped dark gray scoria with moderate vesicularity. Another abundant component corresponds to dark brown pumice, with both fluidal and vesicular textures and high vesicularity degree. Both scoria and brown pumice contain mafic and felsic crystals in the glassy matrix. An argillaceous white material is also present in the sample, less abundant than the previous components. Accidental/accessory fragments together with mafic and felsic crystals and crystal fragments are present in the sample. The andesitic volcanic bombs reach 1.5 km away and have elongated shapes with moderate vesicularity; microscopically they are characterized by a porphyritic texture. The observed phenocrysts are euhedral oligoclase, clinopyroxene and alkali feldspars; the hialopilitic matrix is almost completely made of glass with microlites of plagioclase, alkali feldspars and clinopyroxenes. The dark brown pumiceous fragments are flat and reach up to 10 cm length. They are characterized by light weight because of their high vesicularity. Under the microscope, the dark brown pumice showed porphyritic texture, where phenocrysts represent less than 1 Percent, all euhedral and fragmented phenocrysts (oligoclase and clynopiroxene). Due to its light weight, ability to float, and mineralogy it might be named pheno-andesitic scoria. According to field observations, this ejects were thrown up by a grey plume that preceded the strombolian event. According to the preliminary study of the emitted material and the observations made during the eruption, we can infer an andesitic composition for the magma and vesiculated pumice fragments, which correspond to the initial phase, accumulated at the top of the conduit.

Eruptive history of long-lived active Tokachidake volcano group, southwestern Kurile arc

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Detailed geologic mapping supported by radiometoric age deteminations is important tool to clarify the eruptive history of long-lived arc active volcanoes. Tokachidake is one of the most active volcanoes in Japan, and is a cluster of Quaternary volcanoes. It overlies Late Pliocene to Early Pleistocene rhyolite ignimbrites. The volcano group extends 25 km mainly in the NE-SW direction, consisting of at least twelve volcanic edifices which are 5 to 10 km in diameter. Using detailed mapping and stratigraphy, airborne laser scanner data, and new 33 K-Ar and 16 radiocarbon ages determinations, and geochemical data, we have mapped the 55 geologic units in the area of 270 km^2 centered on the volcano group.

The Tokachidake volcano group can be divided the volcanic evolution spanning approximately 1.0 Ma into three stages -Older, Middle and Younger- on the basis of their radiometric ages, eruption centers and petrologic features. (1) In the Older stage, the products have limited distribution and consist mainly of andesite lava flows that erupted during 1.0 Ma to 500 ka. (2) The Middle stage activity occurred during 300 to 70 ka, and had increased extensively. Five basaltic stratovolcanoes were built in the margins of the volcano group, whereas six andesite stratovolcanoes and a dacite lavas erupted around its center. (3) The Younger stage began around 60 ka, and the active region is concentrated in the central part of the volcano group. The topographical features of each volcanic unit are preserved. The products are composed of basalt to andesite lava flows and pyroclastic fall, pyroclastic flow and debris avalanche deposits with a dacite lava dome. These products are enriched in K_2O relative than those of the Middle stage.

The most characteristic of the eruptive history of the Tokachidake volcano group is that the activity expanded approximately 300 ka and gradually contracted to the center. Then mafic magmas were erupted in the whole area of the volcano group, whereas the intermediate to felsic magmas were only around the center. We could evaluate the long-term volcanic activity in the point of view of this geologic mapping.