V21E MC: 305 Tuesday 0830h

Understanding Volcanoes Through Multiparameter Measurements and Their Interpretation: Martinelli Memorial I

Presiding: **S Falsaperla,** Istituto Nazionale di Geofisica e Vulcanologia**; T Nishimura,** RCPEV, Science, Tohoku University

V21E-01 0830h

The Challenge of Understanding Volcanoes

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While Bruno Martinelli saw the "wonderful and interesting" systems that are volcanoes and their eruptions as a challenge, his interest in studying volcanoes was rooted both in his scientific curiosity and in his experience with their often deadly impact on people. As a system engineer, he knew that it is only possible to understand volcanic processes if we can understand the dynamic properties and movements of the fluids involved as well as the volcanos internal structure. Such understanding must be based on the observations and synthesis of many volcanic parameters rather than just one, such as seismicity. Insights can only come from the joint interpretation of measurements of many different physical and physico-chemical phenomena, as well as observations of a volcanos geological and petrological characteristics and its activity. Rather than basing forecasts of activity changes on phenomenology, Bruno Martinelli took up the challenge to understand the physical processes occuring in volcanoes as a foundation for monitoring and estimating changes in activity.

V21E-02 0845h INVITED

Understanding the dynamics of magmatic systems - evidence from Long Valley Caldera and Kilauea Volcano

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Active magmatic processes produce a wide range of signals that are capable of detection at the Earth's surface by modern geophysical and geochemical instrumentation. The most robust of these signals include spatial-temporal patterns of (1) ground deformation spanning a broad spectrum from gradual secular and quasi-static changes to the high-frequency vibrations associated with seismic waves generated by local, brittle-failure earthquakes and (2) magmatic gas emissions of, most notably, SO2 and CO2. The long records of deformation (in this broad sense) and geochemical data accumulated for Kilauea Volcano on the Island of Hawai'i and in Long Valley Caldera in eastern California exemplify the value of spatially and temporally dense monitoring as a basis for understanding the dynamics of magmatic systems. Kilauea's magma conduit, defined by brittle failure and LP earthquakes, has the form of a narrow, straw-like structure extending from within the lithosphere at a depth of >40 km to a magma chamber centered roughly 5 km beneath the summit crater (Halemaumau). This shallow magma chamber, which consists of a plexus of dikes and sills, is capable of feeding eruptions both within the summit caldera and along the east and southwest rift zones. The current eruption from vents along the east rift zone, which began 18 years ago, appears to be gradually draining this summit magma chamber, as Kilauea's summit has been subsiding about 10 cm/yr since the eruption began. This is equivalent to a volume of about 0.01 km3/yr, 10 percent of the eruption rate of 0.1 km3/yr. Most of the gas released by the magma column escapes through the summit caldera as it ascends from the magma chamber toward the summit and thence through conduits to the active vents on the east rift zone. Indeed, the CO2 flux (about 10,000 tones/yr) from the caldera serves as a proxy for magma flux through the conduit system. Dynamic interaction of the active magma conduit with the hydrothermal system beneath the summit crater produces sequences of shallow LP and VLP earthquakes. Two magmatic systems contribute to the 20 years of unrest in Long Valley Caldera: one beneath the resurgent dome in the center of the caldera and the other beneath Mammoth Mountain on the southwest rim of the caldera. Cumulative uplift of the resurgent dome by 80 cm reflects a volume increase of roughly 0.3 km3 in magma to chamber centered at a depth of 7 to 10 km beneath the surface. Recurring swarms of brittle-failure earthquakes in the south moat follow increased inflation rates with the more energetic episodes associated with intrusions of magma or magmatic brine into the brittle crust. The absence of seismicity at depths greater than 10 km beneath the caldera, however, leaves a question mark for the nature of this magmatic system at mid- to lower-crustal depths. The absence of magmatic gas emissions in the vicinity of the resurgent dome and south moat suggests that the volatile components of this magmatic system remain trapped below an impermeable seal. In contrast, a dike-like distribution of deep LP earthquakes overlain by a volume of brittle-failure earthquakes, including several shallow VLP earthquakes, delineate the magmatic system beneath Mammoth Mountain from mid-crustal depths of 30 km to within 3 or 4 km of the surface. This system, which became activated with a six-month-long earthquake swarm and intrusion beneath Mammoth Mountain in 1989, has continued to produce a diffuse efflux of magmatic CO2 at a rate of 200 to 300 tones/day apparently fed by basaltic magma distributed in a plexus of dikes and sills at mid-crustal depths.

V21E-03 0900h

Possible Fluid-Driven Seismicity Migration in the 1997-98 Long Valley Caldera Earthquake Swarm

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The western south moat of the Long Valley caldera in eastern California has been the site of recurrent earthquake swarms since 1980, the most recent having occurred in late 1997 - early 1998. The 1997/98 seismic episode peaked on November 22, 1997 with 3 >=**M**4.6 and ∼1,000 >**M**1.2 earthquakes in the western south moat. Although the majority of these earthquakes were conventional double-couple events, a few of the events, including the 3 >=**M**4.6 earthquakes, appear to have had significant dilatational components in their source processes (Dreger et al., 2000; Julian et al., 2000). Two-color laser geodolite measurements indicate that local deformation also peaked on November 22, with extension across the caldera's resurgent dome reaching a maximum rate of 2 mm/day (Hill et al., 2001). Concurrently, an anomalous dilatational strain transient was observed ∼12 km west of the western south moat earthquake swarm area that initiated at the time of the first **M**4.6 earthquake (Dreger et al., 2000). These observations have been interpreted as evidence for magmatically-induced fluid injection during faulting. The outstanding question raised by this explanation is the mechanical problem of how shear (∼60° to S_3) and opening (perpendicular to S_3) could appear to occur on the same plane.

To better understand the November 22, 1997 western south moat earthquake swarm and the possible role of magmatically-derived fluids in faulting in the Long Valley area, we relocated these events using a double-difference algorithm (Waldhauser and Ellsworth, 2000), incorporating arrivals from the seismometer at 2 km depth in the Long Valley Exploration Well. The resulting high-resolution locations reveal that in the 23 hours following the first **M**4.6 earthquake on November 22, hypocenters migrated ∼4 km upward and ∼4 km westward along the western south moat fault zone away from the initiation region at ∼9 km depth. The average migration rate was ∼200 m/hour. Overall, the seismicity appears to have formed a pattern of radially expanding earthquake hypocenters, supporting the hypothesis that seismicity on Nov. 22, 1997 may have been triggered by high pore fluid pressure migrating along the south moat fault zone from the hypocentral zone of the first **M**4.6 earthquake.

Dreger, D. S., H. Tkalcic, M. Johnston, *Science, 288*, 122-125 (2000). Hill, D. P., D. Dzurisin, W. L. Ellsworth, E. T. Endo, D. L. Galloway, T. M. Gerlach, M. S. J. Johnston, K. A. McGee, C. D. Miller, D. Oppenheimer, M. L. Sorey, *U.S.G.S. Bull. 2185*, (2001). Julian, B. R., G. R. Foulger, A. M. Pitt, D. P. Hill, P. E. Malin, E. Shalev, *EOS, 81*, F1384 (2000). Waldhauser, F., W. L. Ellsworth, *Bull. Seismol. Soc. Am., 90*, 1353-1368 (2000).

V21E-04 0915h

Mechanics of Volcanic Activity in Long Valley and Kilauea/Mauna Loa Volcanic Areas from Multi-parameter Borehole Measurements

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Multi-parameter borehole instrumentation (high-precision strain, seismic, pore pressure, tilt sensors, etc) in Long Valley Caldera and on Kilauea/Mauna Loa in Hawaii allow exciting new insights into the mechanics of volcanic activity. The new data include real-time observations of; 1) subsurface intrusions leading to surface eruptive activity, 2) intrusions and swarm activity triggered by distant earthquakes, 3) deformation preceding and following very long-period (VLP) earthquakes, and 4) unusual deformation sometimes associated with "normal" volcanic earthquakes. Many intrusive episodes have been observed in their early and final eruptive stages on borehole strain and tilt instruments on Kilauea and Mauna Loa in Hawaii. The largest event on September 25, 2000, was observed out to a distance of 58 km from a source under Kilauea and can be modeled by magma intrusion from this source up and into the east rift system. The October 16, 1999, M7.1 Hector Mine, California, earthquake and the previous June 28, 1992, M7.3 Landers earthquake triggered deformational transients and seismicity in the Long Valley Caldera. The deformation was triggered by the passage of large-amplitude surface waves (3.2 bars) through the region. For the Landers earthquake, diffusive seismicity throughout the south moat occurred simultaneous with the deformation and has been explained as either triggered diffusion of hydrothermal fluids, triggered bubble release from magma, or triggered dike intrusion. For the Hector Mine earthquake the seismicity was localized under the north side of Mammoth Mountain and followed the onset of deformation by 20-30 minutes. Triggered slip and perhaps intrusive opening on a north-striking normal fault at a depth of 6 km beneath the triggered seismicity can explain these data. Total moment release was 3X10E15 Nm, equivalent to about a M4.3 earthquake while the actual seismic moment release was three orders of magnitude smaller. Decay of strain and seismicity occurred over the next five days. Thus, two apparently distinct modes of transient deformation, triggered by large distant earthquakes, have now also been observed in Long Valley caldera. Volcanic VLP events occurring beneath the strainmeter at Devil's Postpile (POPA) are preceded by increasing extensional strain to about a nanostrain in the minute before the event followed by relaxation and, in one case, a net offset of about 0.3 nanostrain after the event. High frequency radiation occurs also with these events. Thus, pressure opening of cracks can generate radiation with both brittle failure and oscillatory low-frequency behavior. To investigate island arc volcanoes, a new program of multi-parameter borehole measurements is planned for Akutan volcano in Alaska.

V21E-05 0930h

Monitoring Fogo Island, Cape Verde Archipelago, for Volcanic Hazard Mitigation

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Fogo Island, in the Cape Verde Archipelago (North Atlantic), with a total area of 476 km2 and a population of about 40000, is an active ocean island volcano raising from an average sea-bottom depth of the order

of -3000m to a maximum altitude of 2820m. All of the 28 historically recorded eruptions (Ribeiro, 1960) since the arrival of the first settlers in the 15th Century took place in Cha das Caldeiras, a 9 km-wide flat zone 1700 meters above sea level that resulted from the infill of a large lateral collapse caldera (Day et al., 2000). The last eruptions occurred in 1951 and 1995, through secondary cones at the basis of Pico do Fogo, the main volcanic edifice. A tall scarp surrounds Cha das Calderas on its western side only, and the eastern limit leads to a very steep sub-aerial slope down to the coastline. With this morphology, the volcanic hazard is significant inside Cha das Caldeiras - with a resident population of the order of 800 - and particularly in the villages of the eastern coast. Because the magma has low viscosity, eruptions in Fogo have scarce precursory activity, and its forecast is therefore challenging. The VIGIL monitoring network was installed between 1997 and 2001, and is currently in full operation. It consists of seven seismographic stations - two of which broadband - four tilt stations, a CO2 monitoring station and a meteo station. The data is telemetred in real time to the central laboratory in the neighbor island of Santiago, and analyzed on a daily basis. The continuous data acquisition is complemented by periodic GPS, gravity and leveling surveys (Lima et al., this conference). In this paper we present the methodology adopted to monitor the level of volcanic activity of Fogo Volcano, and show examples of the data being collected. Anomalous data recorded at the end of September 2000, which led to the only occurrence of an alert warning so far, are also presented and discussed.

URL: http://www.fisica.ist.utl.pt/∼ *sismo*

V21E-06 0945h

GPS and Gravity Surveying at Fogo Volcano, Cape Verde Islands, 1998-2001

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Fogo Island, in the Cape verde archipelago (North Atlantic), is a roughly conical volcanic edifice with 25 Km of base diameter and a summit that reaches an altitude of about 3000 m. Volcanic eruptions in the island are reported since the settlement in the 16th century, at average intervals of about 20 years. In the 20th century the activity subsided, with only two eruptions in 1951 and 1995. Fogo comprises 33000 inhabitants, of which 800 live inside the 9km-wide ancient collapse caldera, which is open towards the East. A joint effort has been made to implement basic monitoring capabilities in Fogo. A permanent network for real-time monitoring of seismicity and tilt was installed in 1999 (Faria et al., this conference). This presentation describes the repeated GPS and microgravity surveys carried out in Fogo island between 1998 and 2001.

Until present, five GPS and three microgravity surveys were made, with a repeat period of about 7 months. A network composed of 23 geodetic monuments, with stable reinforced concrete foundations, was previously implemented for this purpose, covering the entire island with basis lengths between 2 and 8 Kms. For the GPS surveys, seven GPS Trimble 4000 SSE receivers were used, and the observations were processed with Bernese 4.2 software. Two LaCoste & Romberg G gravimeters were used together with the GPS observations for three of the five campaigns.

The results from the GPS surveys show significant vertical and horizontal deformation. The clearest observations are as follows: 1. between Sep 98 and Apr 99, uplift (up to 5 cm) of the points inside the collapse caldera; 2. between Apr 99 and Nov 99, dislocation towards the East of the monuments inside the caldera and on the East coast; 3. between Nov 99 and Jun 00, movement towards the West of the points inside the caldera and on the East coast. The microgravity survey carried out between Nov 99 and Jun 00 points to density increase coupled with surface uplift. Different mechanisms to explain the observations are discussed, namely subsurface magma movements, gravitic instability of the volcanic edifice and variations of the water-table geometry.

URL: http://www.fisica.ist.utl.pt/∼ *sismo*

V21E-07 1020h

Joint Interpretation of Geodetic Data for Volcano Studies: Evaluation of Pre- and Co-eruptive Deformation for the Hekla 2000 Eruption From InSAR, Tilt, GPS and Strain Data

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Currently there are a number of geodetic techniques utilized to study deformation of volcanoes. Frequently results from one individual technique are interpreted alone, although combination of all available data to constrain one unified model has obvious advantages. We present a case study from the Hekla volcano in Iceland, where ground deformation has been measured with optical leveling tilt, electronic distance measurements, borehole strainmeters, Global Positioning System (GPS) geodesy, and with satellite radar interferometry (InSAR). We find that all of the geodetic data are important because of their complementary nature. The InSAR data provide high spatial resolution but only of one component of the deformation field (range-change from ground to satellite) and the time resolution is poor. GPS has long-term stability and provides 3D displacements, but only at a few stations. The leveling measurements provide the longest time-series of deformation for Hekla, while data from borehole strainmeters provide by far the best temporal resolution, but lack long-term stability. By joint interpretation of all these data sets we aim for the most realistic deformation model for the volcano.

We present data spanning the most recent eruption of the volcano from February 26 to March 8, 2000, when about 0.11 km^3 of magma were erupted. The study covers also the repose period prior to this eruption, after an eruption in 1991. An interferogram series, covering the years 1992-2000, holds both pre- co- and post-eruptive image pairs for the 2000 eruption. The deformation signals arise from several different sources. Subsidence of lavaflows due to mainly cooling and compaction is observed in pre-eruptive interferograms. The largest signals are over the 1991 lavaflows, but lava erupted during eruptions in 1980-81 show also considerable subsidence in some interferograms. The amount of subsidence is closely connected to the lava flow thickness and the age (decreasing deformation with time). Widespread volcanic uplift due to magma accumulation in a deep-seated crustal magma chamber is also suggested in pre-eruptive interferograms. The area affected is about 40 km in diameter, but lava subsidence signals are superimposed on the uplift signal, and thereby conceal uplift in the interferograms in an area around the Hekla summit. Preliminary inspection of some of the tilt and GPS data appears consistent with this conceptual model. In co-eruptive interferograms asymmetrical deformation in the summit region is seen, due to injection of a feeder dike for the 2000 eruption. The borehole strain data constrain the co-eruptive deformation well and a model based on these data suggest that during the eruption a 8 km deep magma source fed the eruption and the formation of a feeder dyke that was 4 km long, 5 km heigh, and 0.3 m wide. This model from the borehole-strain will be a starting model for joint interpretation of the interferograms and the other geodetic data that we will present.

V21E-08 1035h

Recent Tornillos Beneath Tongariro Volcano, New Zealand

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Unusual low-frequency seismic events have recently begun to occur beneath Tongariro Volcano, New Zealand. Because the seismic waveforms appear similar to waveforms called ‘tornillos’ which have been recorded at Galeras Volcano in Colombia, and have been found to precede small to medium-sized ash eruptions there by several weeks to months, we are monitoring them closely.

At Tongariro, these events are characterized by small amplitude, monochromatic waveforms that decay slowly with time, features which suggest a source involving magmatic or hydrothermal fluids within a zone surrounded by hard rock. The frequency content of a single event is typically between 1 and 3 Hz and is often found to be peaked at 1.25 Hz. Event durations range from about 10 to 80 s; the appearance of the shorter duration events is identical to so-called LP or long-period events; the LPs and tornillos appear to be co-located so that the only difference between LPs and tornillos is that LPs contain a high frequency onset, while tornillos have a much longer, monochromatic coda.

These events have been identified in the seismograms of the permanent monitoring station KAVZ since at least January, 2001, occurring at the rate of about one per month. Over the past few months (Jun-Aug) the rate of occurence has gradually increased and is now fairly stable at about one event per day.

We have deployed two additional broadband seismometers at close distance to the expected source location. The resulting seismograms show a complex mixture of seismic waves, originating from shallow depth beneath the area of Te Mari craters, located within 0.5–1 km of the nearest station.

The close range broadband records reveal some interesting details about the tornillo source. The tornillo waveform is found to consists of two parts: a low-frequency (f∼1.25 Hz) part and a higher frequency (f>3 Hz) part. The high frequency energy travels at body wave speeds (c∼3.0 km/s) while the low frequency energy travels at the speed of surface waves in the shallow crust (c∼1.1 km/s). Interestingly, the low frequency waves arrive before the high frequency body waves at the closest station. This, and comparison with several LP events suggest a spatial separation of the high and low frequency sources, with the low frequency energy originating at shallow depth and acting as a trigger for the release of tectonic stress at greater depth, in the form of high frequency body waves. We compare the inferred shallow, low-frequency seismic source location with potential gas chemistry changes in the shallow hydrothermal system.

V21E-09 1050h

Monitoring the Eruptive Activity of Popocatpetl Volcano, Mexico: Case Study of Recurrent Episodes of Magma Injection, Passive Evolution in the Magma Reservoir and Sealing of the Plumbing System

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The proximity of Popocatpetl to large populated areas such as Mexico City is a matter of concern due to the geological background of the volcano consisting of a number of plinian eruptions during the last 5 kyr. Before and after reactivation of the volcano in December 1994, an extensive monitoring network has been deployed. This system includes seismic, gas, visual, aerial, satellite, and laharic flow monitoring among several efforts made to understand the eruptive activity. Since the first measurements in 1994, the volcano yielded large SO2 emissions with a historical maximum of nearly 170 ktd during an eruptive crisis in December 2000. CO2 emissions have also been enormous with maximum values of > 270 ktd in March 1999. By using the CO2SO2 ratios and their variation patterns, several magma-injection episodes have been documented, some resulted in lava dome construction and explosive events. In between the magma intrusions, resident magma has been subjected to differentiation processes, among which degassing and crystal growth have produced physical changes in the magma body at depth. As a consequence of viscosity increases, internal pressures have built up resulting in explosions, whose intensity has increased as evidenced by events such as the one occurred on January 22, 2001. The instrumental response to these differentiation processes consists in episodes of volcanic tremor and variation in the daily number of earthquakes together with strong fluctuations in the SO2 emission rate along the day. Processes occurring in the plumbing system of the volcano such as sealing also produce variations in SO2 emission rates and number and type of earthquakes.

V

V21E-10 1105h

Detecting volcanic eruption precursors: A new method using gravity and deformation measurements

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One of the fundamental questions in modern volcanology is the manner in which a volcanic eruption is triggered; the intrusion of fresh magma into a reservoir is thought to be a key component. The amount by which previously ponded reservoir magma interacts with a newly intruded magma will determine the nature and rate of eruption as well as the chemistry of erupted lavas and shallow dykes. The physics of this interaction can be investigated through a conventional monitoring procedure that incorporates the simple and much used Mogi model relating ground deformation (most simply represented by Δh) to changes in volume of a magma reservoir. Gravity changes (Δg) combined with ground deformation provides information on magma reservoir mass changes. Our models predict how, during inflation, the observed $\Delta g/\Delta h$ gradient will evolve as a volcano develops from a state of dormancy through unrest into a state of explosive activity. Calderas in a state of unrest and large composite volcanoes are the targets for the methods proposed here and are exemplified by Campi Flegrei, Rabaul, Krafla and Long Valley. We show here how the simultaneous measurement of deformation and gravity at only a few key stations can identify important precursory processes within a magma reservoir prior to the onset of more conventional eruption precursors.

V21E-11 1120h

The Seismic Velocity In Gas-charged Magma

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Long-period and hybrid events, seen at the Soufrière Hills Volcano, Montserrat, show dominant low frequency content suggesting the seismic wavefield is formed as a result of interface waves at the boundary between a fluid and a solid medium. This wavefield will depend on the impedance contrast between the two media and therefore the difference in seismic velocity. For a gas-charged magma, increasing pressure with depth reduces the volume of gas exsolved, increasing the seismic velocity with depth in the conduit. The seismic radiation pattern along the conduit can then be modelled. Where single events merge into tremor, gliding lines can sometimes be seen in the spectra and indicate either changes in the seismic parameters with time or varying triggering rates of single events.The differential equation describing the time dependence of bubble growth by diffusion is solved numerically for a stationary magma column undergoing a decompression event. The volume of gas is depth dependent and increases with time as the bubbles grow and expand. It is used to calculate the depth and time dependence of the density, pressure and seismic velocity. The effect of different viscosities associated with different magma types and concentration of water in the melt on the rate of bubble growth is explored. Crystal growth, which increases the concentration of water in the melt, affects the amount of gas that can be exsolved.

V21E-12 1135h

Modelling the Time Dependence of Frequency Content of Long-period Volcanic Earthquakes

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Broad-band seismic networks provide a powerfull tool for the observation and analysis of volcanic earthquakes. The amplitude spectrogram allows us to follow the frequency content of these signals with time. Observed amplitude spectrograms of long-period volcanic earthquakes display distinct spectral lines sometimes varying by several Hertz over time spans of minutes to hours.

We first present several examples associated with various phases of volcanic activity at Soufrière Hills volcano, Montserrat. Then, we present and discuss two mechanisms to explain such frequency changes in the spectrograms: (i) change of physical properties within the magma and, (ii) change in the triggering frequency of repeated sources within the conduit.

We use 2D and 3D finite-difference modelling methods to compute the propagation of seismic waves in simplified volcanic structures: (i) we model the gliding spectral lines by introducing continuously changing magma properties during the wavefield computation; (ii) we explore the resulting pressure distribution within the conduit and its potential role in triggering further events.

We obtain constraints on both amplitude and timescales for changes of magma properties that are required to model gliding lines in amplitude spectrograms.

V21E-13 1150h

Damping and Amplification of Seismic Waves in Gas-Charged Magma

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Low-frequency seismic signals are generated at the interface between a solid medium and a magmatic melt. The existence of gas bubbles in the magma introduces a damping mechanism which depends mainly on the gas volume fraction and on the viscosity of the melt. However, in case of a sudden unloading (e.g. by lava dome failure) a decompressional wave propagates through the magma which becomes now supersaturated. Diffusion of gas into the bubbles leads to an exponential bubble growth which is in general frequency dependent. Such a system can be represented by a negative bulk viscosity which results in a net amplification rather than damping of the decompressional wave. Furthermore, the effects of a harmonically varying pressure on the supersaturated melt is explored, as it is caused by seismic tremor and prolongued conduit resonance.

V22A MC: Hall D Tuesday 1330h

Highly Siderophile Element Chemistry of the Earth, Moon, and Planets (honoring John Morgan) II *(joint with P, HG)*

***Presiding:* A Brandon,** Johnson Space Center**; C Neal,** University of Notre Dame

V22A-1002 1330h POSTER

Re-Os Isotopic Characteristics of the Earth's Oldest Preserved Oceanic Crustal Fragments (Isua Supracrustals Belt, W Greenland); A Vastly Disturbed System.

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Variably preserved pillow lavas from the Isua Supracrustals Belt (ISB; Western Greenland) exhibit strongly supra-chondritic Re/Os (range from 2 to 45) and highly radiogenic $^{187}Os/^{188}Os$ isotopic compositions (range from 0.3 to 20.5). Re-Os model ages are geologically meaningless and reflect the disturbances invoked by post-formational metamorphic overprinting and by metasomatic events that were associated with the intrusion of various generations of the precursors of tonalitic gneisses into the ISB. Most prominently, a late Archean (c. 2.8 Ga) tectono-metamorphic event has locally reset the Re-Os clock in high strain domains of the ISB. Disturbance of the Re-Os system was initially caused by Re addition in connection with metasomatic fluid flow during the early Archean (3.65 to 3.81 Ga) emplacement of central dome gneiss precursors and tonalite sheets into the supracrustals sequences. The effects of open system behaviour of the Re-Os system are similarly recorded by the U-Pb and Sm-Nd systems of these meta-basalts, principally revealing the influx of U, Th, Re; LREE and alkaline-rich fluids from the gneisses into the oceanic crustal sequences preserved at Isua (Blichert-Toft and Frei, 2001; Frei et al., in press; Frei and Rosing, in press). Ultramafic lenses with komatiitic chemical affinities within the ISB are equally affected by early addition of Re, but the very much higher Os concentrations (more than an order of magnitude higher than those of the meta-basalts with values ranging from 30 to 150 ppt) did efficiently mask the disturbances in the Os isotope compositions, so that reasonable Re depletion ages (T_{RD}) can still be deduced. The least altered of these ultramafic lenses revealed a T_{RD}) of 3725 Ma and a mantle extraction (T_{MA}) age of 3807 Ma, dates which are compatible with independent U-Pb zircon ages from intrusive tonalitic gneisses (Nutman et al., 1997) and Pb-Pb age constraints from metasomatic minerals of strongly altered meta-basalts (Frei and Rosing, in press). They can be regarded as minimum ages of deposition of the supracrustals. The complexity of post-formational overprinting however makes it difficult to investigate and explore the Earth's mantle geochemical evolution before this time.

Blichert-Toft, J. and Frei, R. (2001) Geochim. Cosmochim. Acta, 65, 3177-3187. Frei, R., Rosing, M.T., Waight, T.E., and Ulfbeck, D.G. (in press) Geochim. Cosmochim. Acta Frei,R. and Rosing, M.T. (in press) Chem. Geol. Nutman, A.P., Bennett, V.C., Friend, C.R.L., and Rosing, M.T. (1997) Chem. Geol., 141, 271-287.

V22A-1003 1330h POSTER

Platinum-Group Elements in Basalts Derived From the Icelandic Mantle Plume -Past and Present.

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Paleogene basalts (∼55Ma) derived from the ancestral Iceland mantle plume and extruded during continental rifting are exposed along the Blosseville Kyst in central East Greenland. These basalts comprise three intercalated series, viz: a low-Ti, high-Ti and a very high-Ti series. The two Ti-rich series are interpreted to represent continental flood basalts formed by low degrees of partial melting (degree of melting F=3-9%) while the low-Ti series are believed to have formed by higher degrees of partial melting (F:15-25%). All three of the East Greenland basalt series are enriched in the PGE, relative to normal MORB. During differentiation of the low-Ti series, Pd increase from 11 to 24 ppb whereas Pt and Ir decrease from 12 and 0.6 ppb to 3 and <0.05 ppb respectively. The primitive basalts (molar Mg#60) of the dominant high-Ti series contain ∼6-10 ppb Pd, ∼7-10 ppb Pt and ∼0.2 ppb Ir whereas the most evolved basalts (Mg#43) contain 25 ppb Pd, 5 ppb Pt and <0.05 ppb Ir. The PGE-rich nature of these basalts is surprising because low degree partial melts are generally S-saturated and hence strongly depleted in the PGE (cf, Keays, 1995). However, our data indicates that all of the East Greenland magmas were S-undersaturated and as they underwent differentiation, Pd behaved incompatibly while Ir and Pt behaved compatibly. Primitive Holocene Icelandic olivine tholeiites contain 120 ppm Cu, 6 ppb Pd, 4 ppb Pt and 0.2 ppb Ir while their picritic counterparts contain 74 ppm Cu, 17 ppb Pd, 7 ppb Pt and 0.3 ppb Ir. Both the olivine tholeiites and the picrites are believed to have formed by high degrees of partial melting (15-25%) which would have exhausted all of the sulphides in the mantle source region and produced S-undersaturated magmas. In Icelandic samples with 10-14wt% MgO, Cu and the PGEs vary systematically between the primitive picrite and olivine tholeiite compositions given above i.e there is an inverse correlation between Cu and the PGEs. This is best explained by mixing between parental olivine tholeiite and picrite magmas. The low Cu/Pd ratio in the most primitive picrite probably reflect derivation from a depleted mantle where Cu was less efficiently retained in sulphides compared to Pd during previous melt extraction episodes. Whithin the analysed suite of olivine tholeiites, Ir decreases from 0.15 to 0.06 ppb, Pd increases from ∼6 to ∼15 ppb and Pt/Pd ratio decreases from 0.8-0.2 during differentiation (7-4wt% MgO); these variations provide further evidence that the olivine tholeiite magmas remained S-undersaturated throughout their differentiation.

To summarize, (1) Continental flood basalts and low-Ti tholeiites in the Paleogene East Greenland flood basalt sequence, as well as Holocene Icelandic olivine tholeiites are PGE-rich relative to normal MORB.