EUG XI

Symposium VPP3

Growth of Volcanic Structures in the Oceans, from Ridge Crests to the Plate Interiors

Convenors

Neil Mitchell
David Pyle

Tuesday PM Session

VPP3 : TUpm25 : G4
Volcanic Morphology Variation on Young Oceanic Lithosphere: Influence of the Mechanical Rigidity of the Plate

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The youngest volcanoes of the Foundation volcanic chain (39°S) were built on a lithospheric plate less than 5 m.y. old near the Pacific-Antarctic ridge axis by the action of a hotspot. The progressive approach of the Foundation hotspot to the spreading ridge over the last 10 m.y. resulted on the building of the edifices upon a progressively younger, and consequently weaker, plate. The area is an ideal target for the study of the influence of lateral variations in the mechanical thickness of the lithosphere on the volcanic morphology. The age of the plate at the time of the formation of the edifices ranges from 5 m.y. in the western part of the study area to zero at the Pacific-Antarctic ridge axis in the eastern part. Estimates of the effective elastic thickness (Te) show that the elastic rigidity of the plate diminishes from around 4 km away from the spreading ridge to nearly zero at the ridge. The spatial variation of Te correlates with a significant change in both the morphology and the volume of the volcanoes, suggesting an important control of the plate thickness on the volcanic processes. Volcanoes emplaced on lithosphere older than 2 m.y. (age at time of loading) are high cones with well formed rift zones, displaying sometimes a flat summit, suggestive of near-sea level position. These edifices are grouped along ridges, but remain well individualised. Edifices built on lithosphere younger than 2 m.y. (age at time of loading) are much smaller and display dome shaped morphologies, with summital calderas. The volcanoes coalesce to form smooth, elongated, continuous ridges. The youngest volcanoes have a morphology similar to that of the volcanoes of the Rano Rahi volcanic field, located west of the axis of the East Pacific Ridge (~17°S) and thought to have been formed on very young lithosphere.

VPP3 : TUpm26 : G4
Rodrigues Ridge and the Central Indian Ridge: Another Type of Hotspot-Ridge Interaction?

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The Rodrigues Ridge is an E-W volcanic structure which extends at 19°S from the Mascarene Plateau (59°30'E) to 100 km East of Rodrigues Island (64°30'E). It is neither parallel to seafloor spreading flowlines nor to the 'absolute' motion of Africa in the hotspot reference frame. ^{39}Ar-^{40}Ar dating of dredged samples has shown that the whole ridge formed at 8-10 Ma (Duncan, 1990), suggesting a rather rapid emplacement between the former position of the Reunion hotspot and the nearest segment of the CIR at 10-8 Ma. This rules out in Morgan (1978) hypothesis that the Rodrigues Ridge was progressively built near the CIR axis, at the end of a 'channeled' asthenospheric flow originating from the Reunion hotspot. Sr, Nd and Pb isotopes show a gradual fading of the Reunion hotspot influence with increasing distance from the Mascarene Plateau (Mellor, personal communication, 1999).

Signs for a more recent activity are the Rodrigues Island, dated about 1 Ma (Duncan, 1990), and a set of en echelon volcanic ridges, the Three Magi and Gasitao Ridges, discovered during cruise Magofond 2 of R/V Marion Dufresne. They extend the Rodrigues Ridge up to the CIR axis. These ridges display a clear sigmoid shape and align along an E-W direction at 19°40'S. Another parallel, less prominent volcanic alignment is observed about 30 km north, at 19°25'S. K-Ar dating (Cassignol method) provides an age of 0.4 Ma for the easternmost Gasitao Ridge and 1.8 Ma for the underlying oceanic crust. This second age is in agreement with the magnetic anomalies. Isotopic compositions are intermediate between those measured on the Rodrigues Ridge and on the CIR axis.

The lack of conjugate bathymetric feature and the age measured on the Gasitao Ridge demonstrate that it was built off axis, in the close vicinity of the CIR. The sigmoid morphology and en-echelon alignment of Three Magi and Gasitao Ridges suggest that they formed in a dextral transtensional environment. Magmas resulting from decompression melting of underlying mantle would have filled opening tension crack-analogs. Repetition of such magmatic events results in increasing volume as ridges get older, in agreement with the morphology. The hotspot contamination would result from either upper mantle-derived partial melts contaminated by Rodrigues Ridge material or magmas which would have sampled a mantle contaminated by the presence of the Reunion plume head for about 55 m.y. This enrichment of the upper mantle has probably favored the partial melting during decompression (Vlastelic, 1998).

Such model for the emplacement of the Gasitao and Three Magi Ridges can be extended to the whole Rodrigues Ridge and to other volcanic structures like the Puka Puka Ridge in the Pacific Ocean (Janney et al., 2000), leading to the definition of another type of hotspot-ridge interaction.

Duncan, RA, *Proc. ODP Sci. Res*, **115**, 3-10, (1990).
Morgan, WJ, *J. Geophys. Res*, **83**, 5355-5360, (1978).
Vlastelic, I, *PhD Thesis, Univ. Bretagne Occidentale, Brest, France*, (1998).
Janney, PE, Macdougall, JD, Natland, JH & Lynch, MA, *Earth Planet. Sci. Lett*, **181**, 47-60, (2000).

VPP3 : TUpm27 : G4
Crustal Structure of Ascension Island from Wide-angle Seismic Data

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The seismic velocity structure of volcanic islands and of the underlying crust provides constraints on the volume, composition and distribution of igneous addition to the lithosphere during their formation, and on lithosphere rheology. Seismic studies to date have focused on large volcanic edifices or chains of volcanoes such as La Réunion, the Hawaiian Islands and the Canary Islands. Less attention has been paid to smaller, more isolated edifices, which are more common. Ascension Island marks the summit of a 4-km-high volcanic edifice with a basal diameter of 60 km lying on 7 Ma oceanic lithosphere 90 km west of the Mid-Atlantic Ridge in the northern South Atlantic. Radiometric dates suggest that the island is less than 1 m.y. old. In May 1999, we conducted a seismic tomographic experiment around the island, during which about 3500 shots from a 6186 cu. in. airgun array were recorded on four ocean bottom hydrophones (OBHs) and 10 three-component seismometers on the island, with a subset of these shots recorded on disposable sonobuoys. We present results from an initial two-dimensional analysis of part of the resulting dataset, focused on a SW-NE line across the island with two OBHs, five sonobuoys and six land stations. Because the island is small, the crustal structure beneath its centre is well constrained by the onshore-offshore experiment geometry.

Away from the volcanic edifice, we observe a velocity structure typical of young oceanic crust, with a ~3 km Layer 2, including a ~500 m low-velocity Layer 2A, underlain by a ~3 km Layer 3. On the flanks of the island, the low-velocity surface layer thickens significantly, perhaps suggesting a component of mass wasting. Beneath the island, the crustal thickness reaches 12-13 km and Layer 3 thickens to 7 km; the lower part of Layer 3 consists of 1-2 km of material with velocities in excess of 7 km/s which could be interpreted as magmatic underplating. Velocity contours in the mid-crust are not depressed beneath the island; this observation suggests that the observed 2-3 km depression of the Moho is not due to flexure, but rather due to magmatic intrusion. We suggest that, despite the young surface radiometric dates, the volcanic edifice was largely formed on or near the ridge axis, by a similar process to that which has formed a large and apparently active volcano ~20 km west of the present-day ridge axis.

VPP3 : TUpm28 : G4
The Origin of the Dome-Shaped Spreading Centers in the Evolved North Fiji Back-Arc Basin: A New Type of Oceanic Accretion?

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The oceanic ridges of the North Fiji back-arc Basin (NFB) present contrasted morphologies along axis as well as between the numerous accretion centers (Central spreading Ridge, South Pandora Ridge and the newly discovered Futuna Ridge (ALOFI cruise on the N/O L'ATALANTE, March 2000). This diversity is illustrated through two extreme cases: a rift valley usually related to slow spreading ridges (MAR type) and an axial dome usually observed at fast to ultrafast spreading ridges (EPR type). The tectonic processes responsible for the morphological variations of the NFB ridges could be similar to those known for the slow (MAR) and fast (EPR) ridges, thus implying important variations of the lithospheric mechanical properties. This hypothesis can be tested by the analysis of bathymetric and seafloor reflectivity maps, together with petrologic, geochemical and geophysical data.

Like for the Mid-Atlantic Ridge, segments of the NFB accretion system characterized by an axial valley can be explained by a typical rifting process: a slow extension applied to a relatively thick lithosphere together with a low magmatic production. On the other hand, segments of the NFB characterized by an axial dome are quite different from those of the EPR. The EPR axial dome is related to a strong magma production and a fast extension applied to a thin lithosphere; it is supported by dynamic and/or isostatic compensation, and presents a typical narrow and smooth morphology attributed to frequent emissions of fluid lavas from axial eruptive fissures. In comparison, the NFB type axial dome is wide, rugged and punctuated with numerous coalescent volcanoes and/or caldeira forming a very reflective volcanic zone. This observation suggests that the NFB axial dome is a volcanic constructional structure, as shown by the flexuration of the bounding lithosphere in response to the axial volcanic load. Thus, this dome seems to be linked to a strong magmatic production and a slow extension applied to an abnormally thick lithosphere with respect to that underlying the EPR. Several examples along BNF ridges show a dome that growths on the bottom of the rift valley, and evolves toward a huge dome where the previous valley is hidden by the volcanic emissions, whereas no variation of the lithosphere thickness and/or spreading rate can be invoked. We propose that the NFB dome-shaped segments define a new type of oceanic accretion, vertical rather than horizontal, characterized by a slow extension, with a strong poorly-focused magma production below the axis.

VPP3 : TUpm29 : G4
The Azores Plateau: An Example of Ridge-Hotspot Interaction

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Bathymetric, magnetic and gravimetric data have been compiled for the Azores platform area, along the Mid-Atlantic Ridge (MAR) axis between 32 and 49ºN and on the flanks up to magnetic anomaly An13 (~38 Ma). The analysis of these data constrains the episodic character of magmatic events connected with the hot spot activity, their timing and their extension along the MAR axis. The Azores hot spot activity began at about An 6 (~20 Ma), a magmatic event which marks the first construction of the Azores plateau, with a relief of more of 1500 m. The plateau continued to grow northward and southward for about 13 Ma, to reach a maximum extension of about 600 km at An 5 (10 Ma). High reliefs (1000 - 2000 m above seafloor) associated to a thicker crust mark An 6 and An 5A (12 Ma) periods. These magmatic pulses propagate along the MAR axis for several hundred kilometres. A rapid (55 km/Ma) southward propagation takes place during the An 5A pulse, intersecting the Pico fracture zone which did not survive the event. After this period of magmatic construction, the Azores plateau rifted apart. Rifting began at about 9 Ma in the north and propagated southward for about 6 Ma. The oceanic crust subsequently formed at the MAR axis presents a roughness and segmentation of a classical slow spreading centre unlike the crust of the plateau which is smooth and does not show any clear segmentation.

These data show that the surface expression of the Azores hot spot is discontinuous, in relation with the relative position of the hot spot and the spreading centre. The construction of the Azores plateau coincides with the superposition of the hot spot plume with the ridge melting zone, whereas its rifting coincides with the progressive shift of these two zones.

VPP3 : TUpm32 : G4
Analysis of Off-axis Volcanism East of the Australia-Antarctic Discordance

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We investigate the structures observed off-axis on the flanks of the South-East Indian ridge (SEIR) between 133°E and 150°E using satellite-derived, free-air gravity anomaly data. These features appear as alignments of small gravity highs, sometimes forming ridges oblique to spreading, located on lithosphere up to 30 Ma. Hypotheses for the formation of these structures include near-axis volcanism, traces of axial propagators, or tectonic deformation. We favor the near-axis volcanism hypothesis for various reasons. The amplitude of these gravity highs is about 20 mGal, similar to that of the near-axis seamounts and seamount chains observed on the flanks of the East Pacific Rise near 18°S, or of the Juan de Fuca and Gorda ridges in the Northeast Pacific. The traces of only three propagators are observed on the northern flank of the SEIR between 128°E and Georges V FZ, so that it is difficult to relate all the gravity high alignments observed on the southern flank to propagator pseudofaults. Also, these highs are not arranged in series of highs and lows as those generated on inner-pseudofaults of overlapping rift propagators with a cyclic rift failure. The gravity highs are mostly observed on the southern flank of the SEIR between 133°E and the Georges V FZ (140°E), on its northern flank between Georges V FZ and 144°E, and on both flanks of the ridge in the corridor near 145°E. Because of the large right-stepping offset at the Georges V FZ, this distribution of gravity highs displays a prominent maximum around 52°S. This location coincides with that of a geoid high, as well as a zone of anomalously low Rayleigh wave seismic velocity near 50°S, 150°E, suggestive of a mantle thermal anomaly beneath the area. Some gravity highs form ridges which are oblique to spreading, oriented about NW-SE on the southern flank of the SEIR, and NE-SW on its northern flank. Such an orientation, combined with the points developed above, suggest that the gravity highs might have formed near the SEIR, above regions of high magma supply, which migrated from east to west.

VPP3 : TUpm33 : G4
Eruptive Fluxes in Magma-Rich Ridge Environments: Constraints from Seamount Size and Shape on the Mid Atlantic Ridge

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Crustal accretion at slow spreading ridges such as the Mid-Atlantic ridge (MAR) leads to the formation of numerous seamounts (Smith and Cann, 1992). Seamount size and shape are indicators of magma volume and flux, respectively, supplied from crustal magma chambers. We have studied two areas of the MAR south of the Azores hotspot, characterized by high magma supply, as inferred from gravity-derived crustal thickness. These two areas are: 1) a prominent seamount chain across segment OH1 (35°N), parallel to spreading direction and extending on both flanks of the ridge; and 2) a rifted volcanic plateau off-axis from segment Lucky Strike (37°20'N). The seamount chain formed at or near axis, as inferred from magnetic data. The plateau resulted from enhanced ridge magmatism from the Azores hotspot. We compare seamount size and shape in both areas to those in other areas along the MAR (the Lucky Strike segment near axis, the 24-30°N region and the Reykjanes ridge). The seamounts on the volcanic plateau are slightly larger than those elsewhere along the MAR, while those along the volcanic chain are 2-3 times higher on average. We thus infer that particularly high magma volumes are supplied from crustal magma chambers to build the seamounts along this chain. This is consistent with a pronounced gravity low underlying the chain, and therefore thicker crust (~ 8 km), and more abundant volcanism than in surrounding areas. The volcanic plateau is associated with an even more prominent gravity low and thus thicker crust (~ 13 km), while its seamounts are smaller on average. We conclude that there is no correlation between magma volumes constructing seamounts and magma supply to the ridge. The seamounts studied in both areas south of the Azores are moderately flat-topped, as those in the rest of the MAR, probably reflecting a similar evolution of magmatic fluxes during their construction.

Smith DK & Cann JR, *JGR*, **97**, 1645-1658, (1992).

VPP3 : TUpm34 : G4
Shallow Mantle Magma Sources in the Tyrrhenian Sea

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The Tyrrhenian Sea is a Neogene to Quaternary oceanic basin developed in the central Mediterranean, partly superimposed on the Alpine-Apennine orogenic belt. The oceanic crust formed during the Pliocene to the Present time in the southern part of the basin and is surrounded by three rifted continental margins: East-Sardinia, North-Sicily and Latial-Campanian-Calabrian margin. To increase our knowledge on the physical properties of the lithosphere-asthenosphere system in the area, we perform surface-wave tomography. New measurements of group velocity associated to phase velocity dispersion curves of Rayleigh waves, obtained from the literature, are our databases in the Italian area. From the tomography maps at different periods, the mean dispersion curves of group and phase velocities are assigned to cells of 1°x1°. We concentrate our attention on the Southern part of the Tyrrhenian Sea, where, to obtain the values of the S-wave velocity as function of the depth, we perform the non-linear inversion of the dispersion data in the period range from 10s to 100s. Accordingly to previous studies, in the central part of the Southern Tyrrhenian Sea, the Moho is very shallow (less then 10 km deep) and the lid is very thin (about 10 km thick) with an S-wave velocity of about 4.2 km/s. In correspondence of the Magnaghi-Vavilov and Marsili huge volcanic structures, below the soft lid there is a very well developed low velocity channel, where partial melting can be as high as 10%. The shallow low velocity layer under Magnaghi-Vavilov extends from about 12 km to about 30 km of depth and the S-wave velocity is in the range 3.2-3.6 km/s, while under Marsili the low velocity layer with an S-wave velocity in the range 3.5-3.6 km/s occupies the depth range from about 23 km to about 45 km. These variable depth shallow mantle magma sources feed the alkaline-tholeiitic volcanism of the seamounts. The large extension of this volcanism is in agreement with the recent sonar images of Marsili and Vavilov, that indicate the existence of volcanic edifices of much larger dimension than believed. Moving towards the coast of Italy, in the cells surrounding the volcanic area, the shallow low velocity layer is absent.

VPP3 : TUpm35 : G4
Thermal Constriction and Slab Tearing at the Origin of a Super-Inflated Spreading Ridge: The Marsili Volcano (Tyrrhenian Sea)

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Recently acquired swath bathymetry of the Marsili Basin has offered an unprecedented opportunity to study the processes of back-arc ocean basin development in the Tyrrhenian Sea. In particular, the detailed morphology of Marsili seamount, a large, strongly elongated volcano located in an axial position within the <2 Myr old, ocean crust floored Marsili basin, is a key to understanding the mechanisms governing lithosphere formation in this young basin. The basin is near circular in shape with diameter in the order of 120 km and is positioned in the southern Tyrrhenian Sea, above the steeply dipping Ionian oceanic slab of Mesozoic age (de Voogd et al., 1992; Finetti, 1996). It is bounded southwards by the Aeolian volcanic arc and the Calabrian accretionary wedge, surface evidence of the north-westerly directed subduction. The most outstanding feature of the basin is Marsili volcano (3000 m high, 70 km long and 30 km wide) which reveals distinctive morphology strikingly akin to the high order segmentation and volcanic landforms described in mid-ocean slow-spreading ridges (e.g. Macdonald et al; 1992; Sempéré et al., 1995).

An explanation is put forward for the occurrence of the large, centrally located volcano with such characteristic morphological features. Marsili volcano is taken to represent a super-inflated spreading ridge resulting from a distinct thermal pulse of increased melt production occurring within the young and immature Marsili basin.

It is proposed that surrounding cooler continental lithosphere thermally constricts ridge propagation and crust production in Marsili basin to the finite scale of Marsili volcano. Thermal constriction also results in a drastic reduction of spreading rate, generating the conditions for a 'locked' ridge, thus strengthening a state of super-inflation and producing the characteristic high-order slow-spreading morphological features.

Increased melt production to feed the super-inflated Marsili ridge is generated by deep, lateral asthenospheric mantle flow produced at the edges of tears that bound the subducting ocean crust of the Ionian plate. The existence of dip-directed tears delimiting the narrow Ionian slab is supported by the geological evolution of the surrounding foreland and Apennine/Maghrebid mountain belt during Early/Middle Pleistocene, i.e. the time of formation of the main, axial part of Marsili volcano. Present-day structure and volcanism furnish direct and indirect surface evidence of the presence and location of the slab tears.

De Voogd B, Truffert C, Chamot-Rooke N, Huchon P, Lallemant S, Le Pichon X, *Geophys. J. Int*, **109**, 536-552, (1992).
Finetti, I, Lentini F, Carbone S, Catalano S, Del Ben A, *Boll. Soc. Geol. It*, **115**, 529-559, (1996).
Macdonald, KC, Fox PJ, Miller S, Carbotte S, Edwards MH, Eisen M, Fornari DJ, Perram L, Pockalny R, Scheirer D, Tighe S, Welland C, Wilson D, *Mar. Geophys. Res*, **14**, 299-344, (1992).
Sempéré, JC, Blondel P, Briais A, Fujiwara T, Géli L, Isezaki N, Pariso JE, Parson L, Patriat P, Rommevaux C, *Earth Planet. Science Lett*, **130**, 45-55, (1995).

VPP3 : TUpm36 : G4
Volcanic and Sedimentary Processes in the Eastern Offshore Flanks of Lipari and Vulcano Edifices (Aeolian Island Arc)

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Multibeam bathymetric and reflectivity data, high resolution sidescan sonar mapping and R.O.V. images have been used to investigate the volcanic and sedimentary processes which affect the eastern offshore flanks of Lipari and Vulcano edifices (Aeolian Island Arc). Six lava flows have been recognized in the north-eastern Lipari offshore and interpreted as the submarine portions of silicic lava flows generated from vents on land. Young pillow lava cones and ridges, similar to the individual elements which make up the principal sites of lava extrusion along the Mid Atlantic spreading ridge (Smith and Cann, 1993) are present north-east of Vulcanello Peninsula. As their oceanic analogues (Head et al., 1996), they have been interpreted to result from dike-fed lava effusions. In particular, lateral dike emplacement in a flank rift zone, controlled by the regional ESE-WNW extension direction (Mazzuoli et al., 1995; Monaco and Tortorici, 2000), can explain the observed volcanic features and partially account, through lateral drainage of a summit magma chamber, for the continuing unrest of La Fossa Caldera area. Primary volcanic elements provide the lateral confinement for the development of the main canyons, which extend offshore from Lipari and Vulcano. Erosion and transport of epiclastic material is prevalent in the canyons, resulting in coarse-grained canyon floors. Conversely, deposition of volcanogenic sedimentary material, likely due to flow spreading and gradient reduction, occurs at the canyon mouths. The influence of the evolution of the emergent island arc on the offshore processes is particularly evident in the area facing the active sector of Vulcano Island. Here, a large input of epiclastic sediments from the emergent volcanic edifice is transferred downslope by subacqueous gravity flows allowing the construction of a volcaniclastic fan within a mainly erosional valley.

Smith DK & Cann JR, *Nature*, **365**, 707-715, (1993).
Head III JW, Wilson L & Smith DK, *J.G.R*, **101**, 28265-28280, (1996).
Mazzuoli R, Tortorici L & Ventura G, *Terra Nova*, **7**, 444-452, (1995).
Monaco C & Tortorici L, *J. Geodyn.*, **29**, 407-424, (2000).

VPP3 : TUpm38 : G4
The Significance of Basaltic Lava Balloons Produced during Submarine Eruptions: Facts from the 1998-2000 Azores Volcanic Event

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The Azores islands are located in the middle of the Atlantic Ocean and rise from the so-called Azores Platform, a deeply irregular submarine area delimited by the 2000 meters bathymetric line. The tectonic setting of the region is dominated by the Azores triple junction, a point where the American, Eurasian and African lithospheric plates meet. This complex geodynamic frame together with the presence of a deep mantle plume explains why seismic and volcanic phenomena are frequent in the area. Since the settlement of the islands, early in the XV century, several strong earthquakes and about 30 volcanic eruptions occurred being sometimes responsible for many deaths and severe damages. The most recent volcanic event started on December 1998 on the Serreta Submarine Ridge, about 10 km west of Terceira island, and lasted for more than one year. This submarine fissural eruption was preceded by some days of low magnitude seismic activity and displayed up to 7 active spots, defining NE-SW and NW-SE trends, in an area with estimated depths between 300 and 800 metres. Lava balloons were the most singular features observed during the eruption. They are void volcanic blocks of basaltic composition with spherical to ellipsoidal shapes and sizes up to 3 metres long that were emerging at the sea surface and kept floating for several minutes until they released the hot filling gas. These peculiar structures are interpreted as the result of the formation of lava blisters at vent level due to the degassing of a very fluid gas-rich magma during lava lakes and/or lava fountain episodes. This remarkable phenomenon may not be so uncommon in submarine eruptions and explain a few existent descriptions of historical submarine eruptions not only in the Azores but also in other volcanic regions.

Tuesday PO Session

VPP3 : TUpo01 : PO
The Mt. Meru Debris Avalanche, Magmatic Versus Tectonic Controls

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Mt. Meru is a 4565 m active stratovolcano in the eastern branch of the East African Rift. The most distinctive feature of Meru is the 4 km wide horseshoe caldera, which was produced by a 7800 BP (Hecky, 1971) collapse event. The debris avalanche deposit is ~15 km^3 and covers a surface area of ~1000 km^2, and ran out to the base of Mt. Kilimanjaro 70 km to the east. This would make the Meru deposit the largest debris avalanche deposit yet identified in Africa. The triggering mechanism (magmatic or tectonic) for the collapse is unclear. Mt. Meru is constructed from inter-bedded ash layers, scoria deposits and thin (5-10 m) lava flows, and hence is inherently unstable.

Although there are no intimately associated primary pyroclastic deposits associated with the debris avalanche (such as pyroclastic flows or directed blasts), there are a series of late mantling pumice fall deposits the western slopes of Meru that may be associated with the collapse event. Wilkinson et al (1986) suggest that these fall deposits were produced during a plinian episode associated with the collapse. Amphibole and sanidine phenocrysts from pumice are currently being dated (Ar-Ar), and will clearly indicate whether these were contemporaneous with the debris avalanche. The magma chamber beneath Meru has certainly been active since the collapse event, and an ash cone and lave dome (from which 3 km long lava flows issued in the last 200 years) have developed in the crater. The volume of the major tephra fall deposit is ~1 km^3, which makes this one of the largest tephra deposits in the EAR.

Mt. Meru lies to the eastern side of the splayed rift that has develop in N Tanzania. Normal faults dominate the topography to the immediate north west of Meru in the Lembolos graben. The major fault scarps in the graben strike WNW, but start to swing westwards before they terminate at the base of Meru. The smaller Oljoro graben (striking N) terminates 10 km SW of the base of Meru. Movement along these active faults may have initiated the collapse of Mt. Meru's eastern flank.

Hecky RE, *The palaeolimnology of the alkaline, saline lakes on Mt. Meru lahar. Ph. D. thesis, Duke University*, (1971).
Wilkinson P, Mitchell GJ, Cattermole PJ & Downie D, *J. Geol. Soc. London*, **132**, 467-484, (1986).

VPP3 : TUpo02 : PO
Stratovolcano Sector Collapse as a Function of Magmatic Intrusion

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The 1980 flank failure and subsequent eruption of Mount St Helens, Washington, brought the process of sector collapse to a widespread audience for the first time. In the last 20 years nearly 400 incidences of such collapse have been recognised world-wide, although the mechanisms remain poorly understood.

Clay minerals commonly occur within the deposits associated with sector collapses. Observation of the deposits around Mt St Helens and Mt Shasta, California, shows that alteration to smectite minerals and extensive fracturing occur within the volcano core, effectively converting the edifice to a residual soil and making the volcanic collapse subject to the principles of soil mechanics.

Unlike the large collapses of oceanic islands, subaerial collapses can be modelled and conform well to conventional landslide models such as Bishop's Method of Slices and Janbu's Non-Circular Method and their predicted resistance to movement. Both of these models show that, despite the slope over-steepening, Mount St Helens was fundamentally stable prior to failure.

Analyses of the seismic forces present at the time of failure indicate that they were not the triggering factor, as is often supposed. Seismically induced landslides are restricted in size by the inertial forces within the potential sliding mass. The M=5.1 earthquake widely taken as being the trigger for the collapse can be shown to have originated as a point source sliding at 15º to the horizontal, making the landslide the cause and not the effect.

Back-analyses of the Mt St Helens collapse regularly ignore the presence of the dacite intrusion that was responsible for the edifice deformation. The reduction of shear strength to a point where failure occurs can be shown to be a function of the internal pressures caused by a combination of super-heating of the hydrothermal system and the pressure of volatiles exsolving from the cryptodome. Slope stability is reduced to marginal values due to excess pore water pressures and failure can occur without the need for additional seismic forces.

VPP3 : TUpo03 : PO
Factors Governing the Volcano-Tectonic Evolution of La Réunion Island: A Morphological, Structural and Laboratory Modelling Approach

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Large Oceanic Islands, such as La Réunion, with Piton de La Fornaise (PdeLF) and Piton des Neiges volcanoes (PdesN), are complex geologic environments where magma input is balanced by gravitational compensation and erosion. Compensation operates by vertical sinking (or doming), slow spreading and sudden collapse. Erosion exploits tectonic structures to alter quickly morphology and produce sediment that forms submarine flanks and the lower volcanic pile. Volcano core rocks are metamorphosed into clays, zeolites and serpentines. This drastically reduces edifice strength, inducing major volcano-tectonic episodes. We use digital elevation models (DEM) and fieldwork data to make a constructional and volcano-tectonic model for La Réunion. We test this with analogue (sand and silicone) and numerical modelling (ELFEN discrete element-finite element). DEM: The island has a faulted, collapsed and eroded core, surrounded by a steep submarine slope with large landslide scars. The lower slopes are dominated by clastic material. The general morphology is compatible with gravity spreading, coupled with rapid eruption and erosion. STRUCTURAL analysis of the PdesN reveals some possible spreading-related normal and thrust faults. The volcano core is extensively brecciated and altered, recording several episodes of very high strain-rate deformation. Some events are undoubtedly related to debris avalanche generation, but fast spreading, major magmatic intrusion and rapid metamorphism events may also be recorded. On PdeLF no neotectonic deformation was found, except on the ‘rift zones’ and upper cone, but geomorphologic evidence indicates significant punctuated deformation in the past. MODELS based on hypothetical volcano rheology and construction reveal that the fault geometry of both PdeLF and PdeN can be produced by gravity spreading. Simple models do not produce observed structure, and complex combinations of ductile zones are required. Weak zones are altered old intrusive complexes, active hydrothermal and intrusive sites, serpentinised rock, or sedimentary layers. These deform actively or are dormant, depending on prevailing thermal and mechanical conditions. We provide a model explaining temporal and geometric variations in gravity tectonics, magmatic activity and erosion/deposition of La Réunion. The volcanoes grow from a central core, surrounded by a sedimentary apron. This is incorporated as a thick basal layer on which latter deposits can spread. This layer is responsible for large submarine debris avalanches. In the volcano core, alteration progressively reduces rock strength. This eventually leads to rapid lateral spreading and/or sector collapses. Both processes brecciate the core. Continued magma input regrows the volcano, (if it is faster than erosion) allowing the destabilisation process to begin again. La Réunion may have undergone many such cycles, each with its own particular variation on the theme. Our model is one step further in unravelling the complex volcano-tectonic history. Further detailed study is necessary to untangle the evolution of the brecciated core.

VPP3 : TUpo04 : PO
Towards a Quantitative Assessment of Volcanic Sediments/Particles in the Atlantic Ocean Basin, I: The Northwest African Passive Margin Volcanic Province

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We present initial results from a quantitative assessment of volcanic particles - ranging from debris avalanches with blocks hundreds of m in diameter to silt-sized turbidites - supplied to the Atlantic Ocean basin - as done for the Pacific (Straub & Schmincke, 1998) - from the NW African margin (Madeira to Senegal seamount chain), especifially from the Canary Islands based on seismic data, on-board and down-hole logging and lithology in 4 holes drilled into the flanks of Gran Canaria during ODP Leg 157 (Schmincke & Sumita, 1998). Volcaniclastic sediments comprise (a) hyaloclastites from the seamount stage; (b) debris flow deposits and debris avalanche fans as well as distal turbidites as in the Madeira Abyssal Plain 1000 km NNW of the Canaries (Weaver et al., 1998); (c) syn-ignimbrite turbidites common around Gran Canaria where more than 25 major ignimbrites erupted between 14 and 10 Ma; (d) fallout tephra layers of lesser volume. Groups a, c and d occur during early and highly evolved stages in the eastern Atlantic oceanic island evolution while flank collapses and the resulting debris avalanches, debris flows and distal turbidites (group b) throughout their evolution (Krastel et al., 2001). On Gran Canaria, the upper volcanic apron to > 60 km consists of c. 50% volcaniclastic sediments, most related to major volcanic or destabilization events (pyroclastic flows, Plinian eruption columns, failure of lava deltas or submarine/subaerial flank collapses). Products of erosion are difficult to quantify. Rapidly accumulated hyaloclastites can be many hundreds of m thick and extend over large distances.

Straub S & Schmincke H-U, *Geol. Rdsch*, **87**, 461-476, (1998).
Schmincke H-U & Sumita M, *Proc. ODP,Sci. Results*, **157**, 443-469, (1998).
Weaver PPE, Jarvis I, LEbreiro, SM, Alibüs B, Baraza J, Howe R & Rothwell RG, *Proc. ODP,Sci. Results*, **157**, 619-634, (1998).
Krastel S, Schmincke H-U, Jacobs CL, Rihm R, Le Bas TP & Alibüs B, *JGR*, (2001).

VPP3 : TUpo05 : PO
Causes of Lava Dome Explosivity: The 1902 and 1929 Eruptions at Mount Pelée (FWI, Martinique)

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Dome-forming eruptions are generally considered as features of effusive style. However, some of them show an explosive character. It was the case for the 1902 eruption of Mount Pelée volcano which produced violent turbulent pyroclastic flows involving the destruction of the town of St. Pierre and the death of 30 000 people. Some years after, during the 1929 dome-forming eruption such violent explosive phases were not observed. Only dome collapse events occurred producing block-and ash-flows. In order to identify the grounds for explosivity of dome-forming eruptions, we compared the products of 1902 and 1929 eruptions of Mount Pelée. The silicic andesite magmas involved in both eruptions have the same initial chemical and mineralogical compositions (Martel and al.2000; Villemant and al.1996): thus, differences in eruptive styles are not controlled by pre-eruptive conditions but by the variations of physical and chemical conditions during degassing and ascent of the magma in the conduits to the surface. The shallow magma evolution is studied through chemical and textural analyses of clasts sampled in the two types of pyroclastic flows. Textural analyses were performed using MEB, TEM and image analysis; major elements and halogens compositions of phenocrysts, microlites and glasses (residual glasses and melt inclusions) were obtained by electron probe and pyrohydrolysis analyses. These clasts display a wide range of lithologies, bulk-rock vesicularities, microtextures and volatile contents in residual glasses. Dense clasts from 1902 and 1929 lava domes have a low residual water content, low groundmass vesicularity and extensive groundmass crystallization including silica minerals. But the 1902 eruption is also characterized by the presence of volatile-rich clasts with high vesicularities (60%) and low micro-crystallization.

Degassing paths of this SiO_2-H_2O-rich magmas of the two eruptions (described in residual volatile contents vs vesicularity and Q-Ab-Or diagrams) are consistent with an open system degassing model. A gradual decrease of vesicularity and progressive densification of the magma is due to gas escape from the magma column and vesicle collapse. Simultaneously, melt crystallization induced by degassing enhances fluid exsolution.

The explosivity of the 1902 eruption may thus be explained by the preservation of low degassed zones in the lava dome in contrast to 1929 eruption. These differences in dome evolutions may be related to a slower magma ascent rate of the magma column during 1929 eruption compared to 1902 eruption, or to rapid variations of ascent rate of different magma batches in 1902 eruption, as it is observed in the on-going eruption at Soufrière Hills, Montserrat.

Martel C, Bourdier JL, Pichavant M & Traineau H, *J. Volcanol. Geotherm.Res.*, **96**, 191-206, (2000).
Villemant B, Boudon G & Komorowski JC, *Earth and Planetary Science Letters*, **92**, 107-123, (1996).

VPP3 : TUpo06 : PO
Plutonic Rocks within Society Archipelago, French Polynesia, South Pacific Ocean

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The volcanic oceanic islands of Society Archipelago exhibit plutonic bodies, though generally in small volumes. The plutonic complexes were unroofed by erosion following caldera collapse, whatever the mechanical processes could have been. Among them, Taiarapu, Tahiti-Nui, Raiatea, Bora Bora, and Maupiti from SE to NW are considered hereafter. (i) Taiarapu (Tahiti-Iti) exhibits a continuously differentiated strongly silica-undersaturated suite from theralite to essexite to nepheline syenite, with DI evolving from 14.4 to 75. (ii) Tahiti-Nui, the largest island, exhibits at Ahititera a 2.1 km^2 plutonic massif constituted by two contrasting alkaline suites (Bardintzeff et al., 1988, Bonin and Bardintzeff, 1989): the strongly silica undersaturated 'theralitic' suite (theralite, essexite, nepheline syenite, DI ranging from 12.7 to 65) overlays the weakly silica-undersaturated 'gabbroic' suite (gabbro, monzonite, syenite, DI from 13.5 to 86 with but a gap between 46 and 69). Additionally, minor cumulative pyroxenite is exposed. (iii) Raiatea displays a compositionally more restricted essexite - monzonite suite (DI from 31.8 to 41.9) (iv) Bora Bora exhibits only scarce essexite (DI = 35.2) (v) Maupiti, the oldest island, contains silica saturated gabbro (DI = 24.2) With the exceptions of Tahiti-Nui, where slightly silica undersaturated rocks are exposed, and of Maupiti, where gabbro reaches silica saturation, the other suites of Society Archipelago are typically strongly silica undersaturated. Their chief mineralogy is governed by clinopyroxene, feldspars, and feldspathoids, while olivine, amphibole and biotite are less abundant and even absent in some types. Incompatible major and trace elements of the more mafic and less evolved rock types yield similar primitive mantle-normalized spidergrams. Slight K, Sr, and Hf negative anomalies, and very weak Sm positive anomaly evidence the same enriched source, reminiscent of the EM II OIB reservoir described in the nearby Tahaa volcanic rocks. On the contrary, Maupiti gabbro yield no specific element enrichment, or depletion, and its overall composition is slightly less rich in LILE and HFSE. Felsic differentiated magmas evolved mainly by fractional [clinopyroxene + plagioclase ±olivine] crystallisation, leading to enhanced element anomalies, either negative by mineral substraction, or positive by accumulation. However, no Eu negative anomalies are recorded in nepheline syenites, suggesting REE behaviour was not controlled only by plagioclase, but also by other (accessory) phases.

Bardintzeff JM, Bellon H, Bonin B, Brousse R & McBirney AR, *J.Volc.Geoth.Res.*, **35**, 31-53, (1988).
Bonin B & Bardintzeff JM, *Bull. Soc. Géol. Fr.*, **8, V, 6**, 1091-1099, (1989).

VPP3 : TUpo07 : PO
Volcanological and Petrological Evolution of Marsili Seamount (Southern Tyrrhenian Sea)

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A swath bathymetric survey followed by sampling were carried out on Marsili volcano, the biggest seamount in the Tyrrhenian Sea. It stands 3000 metres above the surrounding oceanic crust of the 3500 m-deep Marsili back-arc basin and is axially located within the basin. The seamount has an elongated shape and presents distinctive morphology, with the summit zone made up of linear cone ridges and extensive cone fields on its lower flanks. The dredging campaign was carried out to sample the different morphological features of the volcano at water depths varying between 3400 and 600 metres. Most of Marsili seamount is composed by medium-K calc-alkaline basalts, whereas evolved high-K andesites were only recovered from the small cones located on the summit axis zone. The petrological and geochemical characteristics of the least differentiated basalts reveal that at least two varieties of magmas have been erupted on the Marsili volcano: group 1 basalts, having plagioclase and olivine as dominant phases, show lower Al, Ca, K, Ba, Rb, Sr and higher Fe, Na, Ti, Zr respect to a second type of basaltic magma (group 2 basalts) which, reveals the presence of clinopyroxene as additional phenocryst phase. In addition, the two groups of basaltic magmas have different original pre-eruptive H_2O content (group 1, H_2O-poor and group 2, H_2O-rich). Moreover, comparison of the compositional trends and mineralogical compositions obtained from MELTS fractional crystallization calculations reveal that the evolved andesites can only exclusively derive from a low-pressure (0.3 kbar) fractionation of magmas compositionally similar to the least evolved group 2 basalts. Finally, we suggest that the high vesicularity of the basalts sampled at relatively great depths (>2400 m) on the edifice is governed by the H_2O and CO_2 exsolution rather than a feature indicative of shallow depth eruption.

VPP3 : TUpo08 : PO
Volcanic Structure of Giant Volcanic Ridges in the Azores Archipelago

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Volcanism within the Azores region of extension between the African and European tectonic plates has created a series of giant volcanic ridges, notably those forming the islands of Pico and Sao Jorge. In 1999, we collected TOBI deeply towed sidescan sonar and phase-difference bathymetry over a series of these ridges among the central group of the Azores islands. Preliminary analysis has concentrated on a ridge SE of Pico. The data show that the ridge is constructed of many small cones, analogous to terrestrial cinder cones, and small constructional ridges. Some cones are elongated, several kilometres long and aligned with the main ridges. Elongated cones were probably erupted over dykes intruded parallel to the main ridges and are possible evidence for alignment of stress axes within the underlying lithosphere affecting the growth of the ridges. Unlike on the submarine extensions of volcanic rift zones around Hawaii, where cones are flat-topped and have low height-diameter aspect ratio, the Azores cones are sharp or rounded. We interpret this as due to higher volatile contents of lava, ultimately due to the different geometry of melt supply and lack of opportunity for pre-eruption magma degassing in the Azores.

Surface morphologies were classified into hummocky and smooth textures based on the sidescan sonar imagery. Our preliminary results show that ridges tend to have hummocky textures while cones tend to have smooth textures. Over the surveyed depth range (mostly 600-1600 m), the data reveal no strong variation in the relative abundance of these textures with water depth which might have indicated a pressure control on the style of eruption. Variable effusion rate or other factors are therefore inferred to determine the surface textures observed.

VPP3 : TUpo09 : PO
Morphology of Volcanic Islands from Source to Sink

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Volcanic islands represent an outstanding natural laboratory for the study of rapidly evolving landscapes dominated by catastrophic mass wastage and tectonic forcing. The relationships between island landscape process and form can now be constrained with onshore topography and recently available offshore multibeam bathymetry. We examine topographic profiles on open flanks of the Canary Islands across a range of resolutions from volcano top (at 1-3.7 km above sea level) to deep-sea sink (at 4-km depth and 100-km distance from source) in terms of proven geomorphic indices. In particular, we link process and form of recently failed and unfailed, subaerial and submarine terrains on relatively young and old islands. Onshore and offshore evidence shows, for example, that some flank sectors have experienced large-scale collapse involving >100 cubic kilometres. Flanks such as N Tenerife and W La Palma have experienced a series of catastrophic collapse events which have repeatedly reduced the slope, curvature and topographic roughness of the upper flank region. Flanks that are unaffected by recent catastrophic collapse appear to be metastable, and are characterised by relatively steep, rugged terrains which give way to smoothly sedimented seafloor at depths greater than approximately 3 km. Such observations guide the ongoing development of landscape models for these unique settings.

VPP3 : TUpo10 : PO
Chemical and Isotopic Variations in Extrusive Rocks from the Farallon Negro Volcanic Complex, NW Argentina

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The Farallon Negro Volcanic Complex is located in Northwest Argentina and extends over 700 square kilometers. The volcanic complex consists of the remnants of a large stratovolcano intruded by several subvolcanic complexes and was active between 9 and 6 Ma as indicated by Ar/Ar datings (Sasso 1997). The intrusions host several economically important porphyry style Cu-Au deposits which have been of special interest to a number of researchers (Sasso, Llambias, Ulrich). The aim of this study is to characterize the geochemistry of the volcanic rocks and get a better understanding over the evolution of the magmatic system. The field work consisted of detailed mapping of one particular area, as well as the taking several sections perpendicular to the dip of the volcanics. Field observations indicate that the volcanic rocks dip systematically away from a central vent in a concentric pattern. Dating by Ar/Ar sustains a younging away from this vent. A vast majority of the complex consists of alternating basaltic andesites and andesites pyroclastic flows, followed by dacitic pyroclastic deposits at the top of the sequence. Two quantitative analytical techniques have been applied: bulk rock geochemistry and whole rock isotope geochemistry. Bulk rock geochemistry show that SiO_2 content volcanic rocks increases overall with time, but large variations occur on a flow to flow basis. The rocks are clearly calc-alkaline with potassic to shoshonitic affinity. Whole rock isotopic composition indicate that the majority of the volcanic rocks come from an in incompatible element enriched source. From the seven data acquired so far only two samples indicate a less enriched source as apparent from MgO vs Sr 87/86 and SiO_2 vs Sr 87/86 plots. We conclude that throughout the volcanic history various sources were tapped or that the source was rejuvenated by mantle material from various depth.

Sasso AM, *Geological Evolution and Metallogenetic Relationships of the Farallon Negro Volcanic Komplex, NW Argentina*, PhD, 1-207, (1997).
Llambias EL, *Geologia de los yacimentos mineros de Agua de Dinosio (Provinca de Catamarca, Argentina): Revista de la Asociacion Argentina de Mineralogia, Petrologia fy Sedimentologia*, **tomo1**, 2-32, (1970).
Ulrich T, *Genesis of the Bajo de la Alumbrera Porphyry Cu-Au deposit, Argentina: Geological, Fluid Geochemical, and Isotopic Implications*, PhD, 1-842, (1999).

VPP3 : TUpo11 : PO
Granite-Poor and Granite-Rich Orogens: Towards a Dual-Mode of Response to Plate Tectonics

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We present a model of melt productivity resulting from dehydration melting of sandstones and greywackes. The mineral composition of such rocks varies with their tectonic setting. We therefore determine their ability to produce granitic-like melt as a function of the tectonic conditions where they formed. Melt production from sediments resulting from continental basement reworking is low, mostly because of the high quartz percentage they present. Sediments resulting from orogen recycling have also a low melt productivity. The only tectonic setting yielding a large amount of melt (above 40%) corresponds to a magmatic arc setting. Examples from the Bengal or Indus fan sediments, as well as from the ordovico-devonian Old Red Sandtone, UK, or Ordovician sediments from southeastern Australia, are also low fertile source material. Conversely the siluro-devonian sediments from the same area show a high melt productivity, which coincides with a period of intense intrusion of granitic rocks in the Lachlan Fold Belt. We suggest that depending on the tectonic evolution of a region, two modes of plate tectonic may develop, one resulting from the closure of Atlantic-like ocean results in a few production of granites. The second, or Pacific-like margin, remains in a setting of magmatic arc and leads to a production of huge volume of granite and crustal addition. This could lead to a bi-modal tectonic response to plate tectonics.

Wednesday AM Session

VPP3 : WEam01 : G4
Piling Rate and Magmatic Evolution through Time of the Teide Volcano (Tenerife, Canary Islands)

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Pico Teide, the summit of Tenerife (Canary islands), is a large strato-volcano built up to historical time in the large caldera of Las Canadas, U-shaped and opened offshore to the north. It corresponds to a giant landslide. In the volcanic structure, the listric fault, which delimitate the landslide, is marked by a typical breccia formation locally called ‘Mortalon’. Offshore, the products of the landslide were recognized on the sea floor. The listric fault and the Mortalon breccia correspond to a discontinuity along which acts as a major drainage surface. Sub-horizontal galleries have thus been dig in the northern flank of the Teide in order to reach the Mortalon to collect water. We took advantage of one of these galleries at ‘la Gotera’, 4337 m long through the volcanic structure, to sample the whole sequence of the building stage of the Teide Volcano from ‘Mortalon’ breccia up to the ultimate pre-historical activity. Ninety-five successive lava flows have been analyzed for major and trace elements, ten of them distributed in the sequence underwent K/Ar dating in order to describe the magmatic evolution through time and piling rate since the landslide. Results demonstrate that activity resumes immediately after, at 161 ±5 ka ago, with a high rate of emplacement. Within the first 45 kyr, about 2000 m high basanitic sequence was accumulated. Subsequently, the piling rate strongly diminishes with only 600 m of more and more evolved products, up to the trachy-phonolites of the recent activity. This can be explained by the effect of lithostatic pressure due to overlying lavas. While fast magma ascent was favored by deloading, lava accumulation slowed down the extrusion rate, and creates conditions for magma accumulation within a shallow reservoir where differentiation occurred.

VPP3 : WEam02 : G4
Contrasting Submarine Slopes of the Canary and Hawaiian Hotspot Islands

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The submarine flanks of volcanic islands are shaped by volcanic constructional processes, landslides, erosion, sediment deposition and tectonic movements. We use a newly acquired multibeam sonar dataset from the westerly Canary islands (El Hierro, La Palma and Tenerife) to develop a comparison with the Hawaiian islands, which suggests differences in the processes constructing and modifying their flanks. Landslides affect the flanks of both island groups. Debris avalanches (fast-moving shallow landslides) have left smooth chutes and blocky deposits in both cases, but blocks within some Hawaiian avalanche deposits are markedly larger. Slow-moving deep-seated slumps have produced submarine benches and tabular escarpments due to thrust faulting adjacent to several Hawaiian rift zones, but are not well-developed in the Canaries. Although volcanic morphology is partly obscured by sedimentation in the Canaries, we are able to interpret lava terraces around the deep flanks of El Hierro which are similar to those found in the Hawaiian islands. However, cones rather than terraces are the most common volcanic forms in the Canary islands. We discuss the origins of these differences, and what light they may shed on the process of island building and erosion.

VPP3 : WEam03 : G4
Giant Landslides in the Flanks of Volcanic Ocean Islands and Overall Significance in their Evolution, the Canary Islands

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One of the most striking features characterising the submarine flanks of the western Canary Islands and other volcanic ocean islands is the presence of a relief type referred to as hummocky terrain (e.g. Moore et al., 1994; Urgeles et al., 1997). Such element is distinctive of the giant volcanic blocks, which constitute the debris aprons associated with large lateral collapses on the island flanks. These landslides range amongst the largest failures on the earth's surface and may involve considerable portions of the volcanic edifices. In some cases, their inner structure, basal plane, and, hence, volume may be estimated from seismic reflection profiling. In others, their volume can just be assessed from the protuberance engendered by the debris lobes. Side-scan sonar techniques also provide a wealth of data, which allow identifying different landslide lobes and to some extent their relative ages (Urgeles et al., 1999). The western flanks of the Canary Islands of El Hierro and La Palma show several such lobes, one single in the case of the island of El Hierro, and up to four lobes in the island of La Palma. Individual landslide masses may attain up to 150 km^3, while the set of landslides in the island of La Palma represents an overall volume of about 700 km^3, approximately 10% of the volcanic edifice. The features are more dramatic for the subaerial part of the edifices, where single landslides may remove up to one fourth of the islands' volume. Available datings from the landslides on the whole archipelago suggest a link between islands shield phases and landslide age. The ages estimated for the landslides younger than 1 Ma also suggests a landslide recurrence interval of 90 ka in the Canary Islands.

Moore JG, Normark WR & Holcomb RT, *Annu. Rev. Earth Planet. Sci*, **22**, 119-144, (1994).
Urgeles R, Canals M, Baraza J, Alonso B & Masson DG, *J. Geophys. Res*, **102**, 20305-20323, (1997).
Urgeles R, Masson DG, Canals M, Watts AB & Le Bas T, *J. Geophys. Res*, **104**, 25331-25348, (1999).

VPP3 : WEam04 : G4
Submarine and Subaerial Growth Phases of the Canary Volcanic Islands as Seen in Reworked Sediment Sequences

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What is the frequency of mass wasting on volcanic oceanic islands and does this vary through the life of the island? These questions were addressed during the ODP Leg 157 to the Canary Basin. Surprisingly, the abyssal plain, some 600 to 1000 km west of the Canary Islands, revealed an important part of the story. The plain has built at the foot of the continental slope, which is the final destination of large turbidity currents which derive from mass wasting events on both the continental margin and Canary Islands. The source of each turbidite can be determined by its composition, with the Canary Island ones having high magnetic susceptibilities due to increased percentages of magnetic minerals. An increase in the frequency of these volcanic turbidites is associated with the inception of the islands of Gran Canaria, Tenerife (at least 2 phases), La Palma and El Hierro. Data for Gomera is less convincing, but also less well dated. We believe this data shows a strong correlation between rapid island growth during its early shield development associated with a high level of mass wasting of the island flanks. Data from other islands such as Tenerife shows that island growth and mass wasting continue at a lesser rate well beyond the shield phase.

One other distinctive group of turbidites on the abyssal plain has an apparent deep-water origin, (moderate calcium carbonate and low organic carbon percentages), but these have a very pulsed input frequency. These turbidites have low magnetic susceptibilities but occur just before each increase in volcanic turbidites. We believe these to represent early submarine mass wasting of the seabed during the submarine phase of island development. Submarine lavas are much more difficult to erode than freatic lavas generated near to and above sealevel. These non-volcanic turbidites are generated over an interval of about half to one million years, which is similar to the duration of increased volcanic turbidite input. The total submarine and subaerial shield development therefore takes in the order of 2 million years for each of the Canary Islands. We found no evidence of the early history of the eastern islands of Fuerteventura and Lanzarote in the abyssal plain even though drilling of extended back to Eocene age. This may be due to a more localised basin surrounding these two islands prior to 16 Ma.

VPP3 : WEam06 : G4
Numerical and Analogue Modelling of Volcano Flank Spreading: Characterisation of Structure, Morphology and Associated Landslide Activity

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All volcanic edifices are, to some degree, subject to a major destabilising process, that of internal alteration and magma storage, which weakens the central core. The role of this in the context of other volcano-tectonic factors is as yet unclear, however several natural examples of flank deformation and sector collapse can be related to alteration. Here we study structures produced by internal weakening using numerical and analogue models. The analogue experiments use a ductile core (silicone) and a brittle volcano (sand and plaster). The numerical models use elastoplastic materials with viscoplastic properties, and are run on ELFEN (discrete element-finite element) software. Both approaches reveal that the edifice develops characteristic morphology and structures. A distinctive concave/convex - concave profile appears on the flanks. Preferential spreading directions occur when the core is not symmetrically centred. Such spreading (which we call type 1) is associated with normal faults behind the summit and thrusts at the front of the slumping sector. Spreading (type 2) in all directions produces narrow radial grabens and a circumferential thrust region. Ductile core dimensions and volume have the strongest control on deformation style. Interestingly, deformation can occur even for small volume fractions of ductile material (<10% of the volume's cone). Deformation produces small landslides where the slopes steepen in the convex zone, or over thrusts. Larger collapses can not be reproduced as the ductile analogue material can not fail, but are likely in nature. Numerical DEFT models using shear softening do produce edifice scale shears that are sites for major collapse. We compare the modelling results with the morphology of several oceanic volcanoes. For example, on La Réunion island, Piton de La Fournaise has structures comparable to type 1 asymmetric spreading and, while the morphology of Piton des Neiges may be a result of type 2 symmetric spreading. Some of the plateau features previously explained as calderas may also be the result of this slow type of deformation. On Aoba (Vanuatu) there is a wide summit plateau; the flanks show slight steppening and arcuate structures similar to those seen in models. These and other examples lead us to suggest that deformation by flank spreading, associated with hydrothermal weakening, is common. The models indicate that it can be a rapid process capable of drastically changing the edifice morphology and creating large failures.

VPP3 : WEam09 : G4
The Model of Strike-Slip Induced Volcano Deformation and Instability and its Application to Mount Bao, Philippines

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Mount Bao is a stratovolcano in Leyte, Philippines, directly overlying the active left lateral Philippine fault. Deformational structures of Mount Bao were investigated to determine their relationship with the movement of the Philippine fault. The structures were compared with previous analogue sand cone models of volcanoes on top of strike-slip faults that showed a unique pattern of structural deformation. This pattern of deformation includes a summit graben, sigmoidal surface features,cone displacement and elongation, reverse faults, normal faults, and intense fracturing. Consequent to the formation of these structures and continuous strike-slip movement, landslides occur on the flanks of the cone. In plan view, these landslides are oriented at a slightly oblique angle relative to the underlying strike-slip fault. The study shows that deformational structures and landslides developed in Mount Bao are consistent with those predicted by the analogue sand cone experiments. In addition, we note in Mount Bao the presence of both pressure ridges along the fault, and sag ponds and pull apart structures at the base of the summit graben. These ridges and pull apart structures form topographic highs and lows that are also observed in photographs of the analogue sand cone experiments but have not been reported previously.

Duquesnoy Th, Barrier E, Kasser M, Aurelio M, Gaulon R, Punongbayan R, Rangin C, & French-Philippine Coorepration Team, *Geophysical Research Letters*, **21**, 975-978, (1994).
Lagmay AMF, van Wyk de Vries B, Kerle N, & Pyle DM, *Bulletin of Volcanology*, (2000).

VPP3 : WEam10 : G4
Large Scale Flank-Collapses during the Activity of Mount Pelée

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On the basis of geological and geomorphological data, Vincent et al. (1989) have identified a horseshoe-shaped structure on the southwestern flank of Mount Pelée (Martinique island, Lesser Antilles arc). This structure, 6 x 3.5 km, has been interpreted as resulting of a flank-collapse event, but no associated debris avalanche deposits were observed at the time. New geological studies constrain the extension of this structure and lead to identify two other horseshoe-shaped structures on the same flank of the volcano. In addition, new high resolution geophysical data obtained offshore during the Aguadomar cruise (Dec 1998-Janv 1999; R/V l'Atalante) have revealed several debris avalanche deposits on the submarine western flank of Mount Pelée and in the Grenada basin. We can trace these submarine deposits to the different structures identified on land and confirm the occurrence of repeated flank-collapse events. An extensive deposit (600 km^2), with relatively smooth morphology, is clearly identified on the bathymetry with a distinct front between the isobaths 2800-2900 m. It is located in continuity with a well marked erosive channel on the submarine flank of Mount Pelée and with the structure identified by Vincent et al. (1989) for which the extension of the northern rim was modified. This event is dated about 25000 years. A younger deposit, lying above the first one and having a smaller extension (60 km^2), has a characteristic hummocky morphology without sedimentary blanket. It corresponds to a recent horseshoe-shaped structure on land, 4 x 2 km, included inside the first one. Debris avalanche deposits are also recognized inside and at the mouth of the depression. The age of this event is probably less than 10000 years. Finally, we can also identify a third deposit, below the two mentioned above which extends further into the Grenada basin. Where not recovered by the other debris avalanche deposits, it shows an important sedimentary blanket attesting of its older age. This deposit can also be correlated with a third horseshoe-shaped structure whose northern rim only is preserved.

These three flank-collapse produced debris avalanches which all flowed to the Caribbean sea towards the Grenada basin. These repeated instabilities of the southwestern flank of Mount Pelée are due to the important east-west asymmetry of the island with western aerial and submarine slopes averaging 20% contrasting with the much gentler (5%) eastern slopes. It results from progressive loading by accumulation of volcanic products on the steep western slopes of the volcanoes and development of long term gravitational unstabilities. Meteoric and hydrothermal fluid circulations on the floor of the first flank-collapse structure also create a weakened hydrothermalized area which favours the recurrence of flank-collapses.

Vincent PM, Bourdier JL & Boudon G, *J. Volcanol. Geotherm. Res.*, **38**, 1-15, (1989).

VPP3 : WEam11 : G4
Evidence for a Differenciated Ignimbritic Activity Ending the Building-Stage of Tahiti (French Polynesia)

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We present the results of new geological investigations carried out on the island of Tahiti (French Polynesia). Mapping and selective sampling were performed on the northern part of the main island (Tahiti-Nui), in order to better describe the final stage of edification. According to Gillot et al. (1993) and LeRoy et al. (1993), the functioning of an E-W rift-zone around 850 ka induced a collapse process that decapitated the primitive shield-volcano. The depression thus created was filled by a second shield, on which we particularly focussed. The base of this sequence is constituted by thick, vesicular and brecciated lava, indicating a rapid decompression. They are overlaid by more fluidal and de-gassed flows, which display an essentially basanitic composition. However, the end of the building-stage is represented by a thick columnar ignimbrite-like formation, observed in the upper part of the Orohena massif. These differenciated products were sampled as pebbles in the E-W Vaitamanu valley, which is incised at the limit of the two shields. They have been dated by the K/Ar Cassignol technique at around 480 ka. The petrographical and geochemical characters of these rocks are compared to the syenitic members found in the same valley. It indicates that the Orohena evolved as an independent northern edifice fed by a magma chamber, which is presently partially exposed to the South, due to erosion. Moreover, the presence of less-evolved magma blebs in these volcanic products highlights a mixing process. This indicates a late re-injection of a more basic magma in the reservoir, probably triggering this violent eruption. Such an episode marks the finishing hot-spot related main activity on Tahiti-Nui, although a subsequent post-erosional effusive activity has been identified around 200 ka in the northern valleys.

Gillot PY, Talandier J, Guillou H & LeRoy I, *International Workshop on Intraplate Volcanism: The Polynesian Plume Province, August 2-7, Papeete, Tahiti*, (1993).
LeRoy I, Turpin L, Guillou H, Chiesa S, Gillot PY & Guichard F, *International Workshop on Intraplate Volcanism: The Polynesian Plume Province, August 2-7, Papeete, Tahiti*, (1993).

VPP3 : WEam12 : G4
Seismic Imaging of the Caribbean Plateau Shows the History of Growth of the Volcanic Structures of a Large Igneous Province

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A multichannel seismic survey performed in the Venezuela Basin of the Caribbean Sea Provides images of the structures within a Large Igneous Province. The Caribbean plateau, thought to have formed as the result of hotspot activity in the Pacific, reaches a thickness of 20 - 25 km. A variety of volcanic edifices is observed in the seismic profiles, including massive mounds, submarine sheet flows, dipping wedges, and seamounts. The tectonic history of the Caribbean plate as it moved from the west into a position between the North and South American plates, is reflected in deformation of the volcanic plateau. Some of this deformation appears to been imposed during the emplacement of volcanic flows; a story told by their stratigraphy.

VPP3 : WEam13 : G4
Mapping Weak, Altered Zones with Aerogeophysical Measurements at Mount Rainier, Washington: Implications for Catastrophic Collapse

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Hydrothermally altered rocks can weaken volcanoes, increasing the potential for catastrophic sector collapses that can lead to far-travelled, destructive debris flows. Evaluating hazards due to alteration is uncertain because alteration has been mapped on few active volcanoes and because the distribution and severity of subsurface alteration is largely unknown on any active volcano. At Mount Rainier, collapses of hydrothermally altered edifice flanks have generated numerous far-travelled debris flows and future collapses would threaten now densely populated areas. Preliminary geologic mapping and remote sensing indicate that exposed alteration is contained in a dike-controlled east - west belt passing through the summit. However, new helicopter-borne electromagnetic and magnetic data, combined with detailed geologic mapping, reveal that appreciable thicknesses of mostly buried altered rock lie mainly in the upper west flank of Mount Rainier, identifying this as the most likely source for future large debris flows. Negligible highly altered rock lies in the volcano's core, which may impede collapse retrogression and limit volumes and inundation areas of future debris flows. High-resolution geophysical and geologic observations yield an unprecedented view of the 3-D distribution of collapse-prone altered rock, and the approach has potential application to hazardous volcanoes world-wide (Finnn et al., 2001).

Finn, CA, Sisson, TW & Deszcz-Pan, M, *Nature*, (2001).