Collaborative Research Centre
SFB 574

Volatiles and Fluids in Subduction Zones: Climate Feedback and Trigger Mechanisms for Natural Disasters

The Lübeck Retreat

Final colloquium of SFB 574
May 23-25, 2012
Program & abstracts

GEOMAR
Helmholtz Centre for Ocean Research Kiel

PROGRAM - SFB retreat 2012, Lübeck

Wednesday May 23		Thursday May 24		Friday May 25	
		08:00	Breakfast	08:00	Breakfast
			Seismogenesis & fluids		Hazards & Climate
		09:00	DeShon	09:00	Walter
		09:15	Schwartz	09:15	Gilbert
		09:30	Arroyo	09:30	Kutterolf
		09:45	Abers	09:45	Krüger
		10:00	Brasse	10:00	Timmreck
		10:15	Grevemeyer	10:15	Oppenheimer
		10:30	POSTERS + coffee	10:30	Coffee
					Future of SZ research
11:00	Bus departure			11:00	Oncken
			Deep slab changes	11:15	Götze
		11:30	Phipps-Morgan	11:30	Ranero
		11:45	Rüpke	11:45	Vannucchi
		12:00	Holzheid	12:00	Morgan
		12:15	Halama	12:15	Conclusion
	Lunch on bus	12:30	Lunch	12:30	Return trip
13:45	11 years of SFB		Arc magmatism		
		14:00	Pearce		
	Forearc processes	14:15	Kay		
14:30	Saffer	14:30	Gazel		
14:45	Hensen	14:45	Folguera		
15:00	Silver	15:00	Rabbel		
15:15	Scholz	15:15	Selles		
15:30	POSTERS + coffee	15:30	POSTERS + coffee		
16:30	Treude	16:30	Jacques		
16:45	Liebetrau	16:45	Gill		
			Hazards & Climate		
17:00	Thiel	17:00	Wehrmann		
17:15	Völker	17:15	Schmincke		
17:30	Geersen	17:30	Mora Stock		
17:45	Tassara	17:45	Hansteen		
18:00	end of session	18:00	end of session		
19:00	Icebreaker party	19:00	Conference dinner		
20:00	Dinner				

ORAL PRESENTATIONS - SFB retreat 2012, Lübeck

Wednesday May 23

13:45 Hoernle: 11 years of SFB research

14:30 Saffer & Lauer: Dewatering, Devolatilization, and Fluid Expulsion Patterns at Subduction Forearcs: Source Regions, Systematic Behaviors and the Role of Splay Faults

14:45 Hensen: Geochemistry of (forearc) fluids

15:00 Silver et al.: Unusual fault pattern and abundant gas and fluid venting off southern Costa Rica, along the trajectory of the subducting Quepos Ridge

15:15 Scholz: Submarine weathering and subduction dewatering across the Central Chilean forearc (~36°S)

16:30 Treude et al.: Biogeochemical characterization of newly discovered seeps in the Concepción Methane Seep Area, Chile

16:45 Liebetrau et al.: Time scales and potential controls of focused fluid flow at circum-Pacific margins: deciphering microbially mediated carbonates from micron to global perspectives

17:00 Thiel: Using biomarkers in carbonates to study microbial methane turnover at cold seeps

17:15 Völker et al.: Tectonic control on submarine mass wasting off Central Chile

17:30 Geersen et al.: Segmentation of the 1960 Great Chile (Mw 9.5) and the 2010 Maule (Mw 8.8) earthquakes controlled by a giant submarine slope failure

17:45 Tassara et al.: Persistent asperities of the megathrust ruptured by the Mw8.8 2010 Maule earthquake: spatio-temporal analysis of seismicity and relation with subduction zone structure

Thursday May 24

9:00 DeShon & Moore-Driskell: 3D double difference tomography of the seismogenic zone beneath Costa Rica and Nicaragua

9:15 Schwartz: Slow Slip and Tremor at the Costa Rica Margin and Comparisons With Other Subduction Zones

9:30 Arroyo et al.: 3-D Velocity Structure and Seismotectonics prior to the 2010 Chile Earthquake (Mw 8.8) from an Amphibious Seismological Network

9:45 Abers et al.: Relating seismic observables to fluid migration in subduction zones

10:00 Brasse: Resolving deep-crustal magma reservoirs beneath the South Chilean and Nicaraguan volcanic arcs with magnetotelluric soundings

10:15 Grevemeyer: Bending-related faulting and mantle serpentinization at deep-sea trenches

11:30 Phipps-Morgan: Bend-Faulting, Serpentinization, and Mantle Recarbonization at Oceanic Trenches

11:45 Rüpke et al.: Numerical modeling of volatile cycling beneath subduction zones

12:00 Holzheid: Gain and loss of volatile and fluid-mobile elements in subduction zones: a combined field-based and experimental approach

12:15 Halama: Nitrogen recycling in subduction zones

14:00 Pearce: Birth and Death of Subduction Zones: The Geochemical Evidence

14:15 Kay: Geochemical and Seismological Evidence for Forearc Crust and Mantle Removed by Forearc Subduction Erosion Entering the Mantle Wedge and the Arc Magma Source

14:30 Gazel et al.: The extensive record of Galapagos-tracks interaction with the Central American subduction system: A natural laboratory for the evolution of continental crust

14:45 Folguera et al.: Neogene evolution of the Northern Patagonian Andes: arc development and associated deformational stages (36-43ºS)

15:00 Rabbel et al.: From the Valdivia Fracture Zone to the Villarrica volcanic complex - seismic evidence of a link between subducted oceanic faults and volcanism

15:15 Selles: General geochemical trends and local compositional diversity in the SVZ

16:30 Jacques et al.: Along- and across-arc geochemical variations in the Southern Volcanic Zone, Chile

16:45 Gill et al.: Arc magma geochemistry accompanying collision: Molucca Sea, Indonesia, and West Bismarck arc, Papua New Guinea

17:00 Wehrmann et al.: On the probability of future plinian eruptions at the Central American Volcanic Arc: a statistical time series analysis

17:15 Schmincke: Some roots of the SFB 574 theme: Impact of natural disasters on society: Acahualinca and Nejapa

17:30 Mora Stock et al.: Multiparameter surveillance of the Llaima and Villarrica volcanoes (Southern Chile): The near real-time approach

17:45 Hansteen et al.: Strong variations in degassing rates at Villarrica Volcano (Southern Chile): Consequences for deep-seated processes

Friday May 25

9:00 Walter: Multi-scale volcano deformations in the Andes observed by InSAR

9:15 Gilbert et al.: Post-glacial time series of explosive eruptions and associated changes in the magma plumbing system of Lonquimay Volcano, South Central Chile

9:30 Kutterolf et al.: Bromine in Plinian eruptions: A paleo-ozone killer?

9:45 Krüger et al.: Modelling the climate effects of explosive eruptions at the Central American volcanic arc for the last 200 ka

10:00 Timmreck: The climate impact of the Young Toba Tuff eruption: An Earth System model approach

10:15 Oppenheimer: The 2011 Nabro eruption, Eritrea: a preliminary report

11:00 Oncken: Earthquakes, peninsulas, fluids, and climate - or: what controls plate margins at the human time scale?

11:15 Götze: MEDACOR - an aero-geophysical offspring of the SFB 574 in Costa Rica

11:30 Ranero et al.: An overview of ongoing studies on the lateral changes of the plate-boundary structure of Middle America, the 3D multichannel seismic experiment at the CRISP area, and the north Chile region

11:45 Vannucchi: CRISP A expeditions: synthesis of key results from IODP Exp. 334 and introduction to IODP Exp. 344

12:00 Morgan: NSF GeoPRISMS Program: Amphibious Continental Margin Studies Around the World

POSTERS - SFB retreat 2012, Lübeck

Arroyo et al: Interplate seismicity at the CRISP site: the 2002 Osa earthquake sequence

Baese & Schenk: Repeated brittle deformation under blueschist- to subgreenschist-facies conditions during exhumation of subducted oceanic crust (Bantimala Complex, Sulawesi)

Burkert et al.: Along-arc variations in magma chamber depth of large explosive eruptions in Central America: constraints from fluid inclusions and mineralogy

Gilbert et al.: Magmatic evolution and volatile inventory of the Lonquimay Volcano, South Central Chile

Halama et al.: Magmatic signatures and metasomatism in the high-pressure metamorphic Raspas Complex, Ecuador

Iyer et al.: Control of reaction kinetics on mantle serpentinization and double Benioff zones

Lücke et al.: Density Structure and Geometry of the Costa Rican Subduction Zone from 3D Gravity Modeling and Local Earthquake Data

Lücke et al.: Density Structure of the Central American Lithosphere from Satellite Derived Gravity Data: highlighting the need for data acquisition at a level between the Earth's orbit and its surface

Metzner et al.: Southern Hemisphere Climate Response to an extremely large tropical Volcanic Eruption: Simulations with the MPI-ESM

Metzner et al.: Radiative Forcing and Climate Impact of explosive Central American Volcanic Arc Eruptions for the last 200 ka

Mora-Stock & Bravo: Automatic classification of volcanic-seismic signals using ensemble methods

Mora-Stock et al.: Comparison of volcano-seismic activity in Llaima and Villarrica before and after the Maule M8.8 earthquake in Southern Chile

Mora-Stock et al.: Volcano seismicity at Villarrica volcano

Portnyagin et al.: Contrasting compositional trends of rocks and olivine-hosted melt inclusions from Cerro Negro volcano (Central America): Implications for decompression-driven fractionation of hydrous magmas

Rabbel et al.: From the Valdivia Fracture Zone to the Villarrica volcanic complex - seismic evidence of a link between subducted oceanic faults and volcanism

Scudder et al.: Dispersed Volcanic Ash in Sediment entering NW Pacific Ocean Subduction Zones: Towards a Regional Perspective

Schindlbeck et al.: Holocene post-caldera magma evolution of Llaima volcano, Chile

Springer: SFB data management

Steeb et al.: Response and efficiency of the benthic microbial methane filter under non-steady state conditions

Thorwart & Rabbel: Non-volcanic tremor in Costa Rica: b-values, moment release and tidal modulation

Toohey et al.: The influence of eruption season on the global aerosol evolution and radiative impact of tropical volcanic eruptions

Villar-Muñoz et al.: Heat flow in the Southern Chile Forearc controlled by large-scale tectonic processes

Wehrmann et al.: On the fluid-mobility of molybdenum, tungsten,and antimony in subduction systems

Wehrmann et al.: Sulphur and chlorine geochemistry of mafic to intermediate tephras from the Chilean Southern Volcanic Zone (33-43°S) compared with those from the Central American Volcanic Arc

Abstract ordered alphabetically by first author

Relating seismic observables to fluid migration in subduction zones

Abers, G.A., K.M. Fischer, J.G. Hirth, B.K. Holtzman, D. Wiens and T. Plank

Seismic images provide quantitative information about the physical state of the mantle. In subduction zones, a number of recent high-density broadband seismic field experiments provide images and analyses of the down-dip changes to the slab surface, the subarc melting region of the mantle, and the cold forearc nose. However, the implications of the measured quantities (P and S velocities Vp and Vs, attenuation Qp and Qs, and measures of seismic anisotropy) for the quantities of geodynamic interest (such as temperature, melt, water content, and composition) are not unique. We seek to systematically improve our understanding of the interrelationships between seismic and geodynamic parameters, leveraging seismic data collected from dense arrays in several subduction zones. These data compare well with arc chemistry, revealing complementary patterns between chemistry and seismology along strike in Central America and down dip in the Marianas. In particular, at the slab surface, receiver functions and other mode conversions show a transition from high amplitude conversions at the shallow thrust zone, indicating a weak and probably over-pressured subduction channel, to a deeper region that can be characterized by subducting uneclogitized crust. Elsewhere and deeper, the effects of steep thermal gradients become more significant in seismic images. In the wedge, low seismic velocities and high shear attenuation (1/Qs) indicate elevated temperatures, consistent with those recorded in the compositions of arc basalts. In some subduction zones seismic velocities (e.g., Vp/Vs) may indicate the presence of melt or high water content, although quantifying such interpretations remains difficult due to uncertainties in the mechanism by which melt affects seismic properties. Comparisons of 1/Qs, Vp, and Vs have potential to discriminate between the effects of melt, temperature and composition, particularly when complemented by H_2O contents measured in arc melt inclusions. Self-consistent comparisons of all these data help interpret imaged variations between Nicaragua and Costa Rica and the Marianas are beginning to show evidence for the places at which fluids leave the slab, and the pathways they take to volcanic arcs.

3-D Velocity Structure and Seismotectonics prior to the 2010 Chile Earthquake (Mw 8.8) from an Amphibious Seismological Network

Ivonne G. Arroyo [1,2], Ingo Grevemeyer [1,2], Ernst R. Flueh [1,2], Helene Kraft[2], Eduardo Moscoso [1,2], Diana Comte[3], Martin Thorwart [1,4], Yvonne Dzierma [1,4], Wolfgang Rabbel [1,4]

(1) SFB 574, University of Kiel, Kiel, 24148 Germany
(2) GEOMAR, Wischhofstr. 1-3, Kiel, 24148 Germany
(3) Departamento de Geofísica, Universidad de Chile, Santiago, Chile
(4) Institute of Geosciences, Christian Albrechts University, Kiel, Germany

Within the project SFB574, an “amphibious” network of 15 ocean bottom seismometers and 27 land stations was operated from April to October 2008 along 350 km from the outer-rise to the magmatic arc. Additional readings from 11 permanent stations of the Chilean Seismological Service were included in the database improving onshore coverage. One of the main goals of the project is to gain a detailed image of the crustal and upper mantle structure and the seismogenic zone by analyzing earthquake distribution and combined passive and active source seismic tomographic images.
To achieve precise earthquake locations and to serve as an initial model for local earthquake tomography, we derived a P- and S-wave minimum-1D model using a very high-quality subset of 340 events (GAP ≤ 180°, at least 10 P-wave and 5 S-wave arrivals) and velocity information from a wide-angle profile shot in the area. Most of the ~1200 earthquakes recorded in our target area were originated within the subducting slab down to ~140 km depth, with a higher concentration beneath the main cordillera, at depths of 80-110 km. Fewer events were generated at the outer-rise, at depths of ~20-40 km, closely following the NE-SW trend of the oceanic plate faulting.
The database was relocated using the minimum 1-D model and a subset of 400 events (GAP ≤ 180°, at least 8 P-wave arrivals) with ~7000 observations was selected to perform a P-wave tomography. Our results confirm the strong, lateral velocity gradient in the forearc seen in previous works along the margin, interpreted as the transition between a paleoaccretionary complex and the seaward edge of the Paleozoic continental framework. The downdip limit of the interplate seismicity previous to the

great earthquake was aparently controlled by a low-velocity anomaly at ~40 km depth, shallower than the deeper extent estimated by geodetic modeling of the rutpture and from aftershocks relocation for the Maule earthquake. The interplate seismicity nucleated from ~40 up to ~20 km depth, and did not extend up to the 100°C isotherm. It was sparse except for a cluster of ~1200 km2 offshore and SW of Pichilemu town, within an area where a locking ≥ 75 % before the great earthquake has been estimated. The deep outer-rise seismicity and the low velocities on top suggest considerable hydration of the downgoing plate.

Interplate seismicity at the CRISP site: the 2002 Osa earthquake sequence

Arroyo I.G.[1,2], I. Grevemeyer [1,2], R. von Huene [3], S. Husen[4], C.R. Ranero[5], E.R. Flüh [1,2]

[1]SFB 574, University of Kiel, Kiel, 24148 Germany
[2]GEOMAR, Wischhofstr. 1-3, Kiel, 24148 Germany
[3]Department of Geology, University of California, Davis, CA, USA
[4]Swiss Seismological Service, Zurich, Switzerland
[5]ICREA, Institute of Marine Sciences, CSIC, Barcelona, Spain

The Costa Rica Seismogenesis Project (CRISP) is designed to explore the processes involved in the nucleation of large interplate earthquakes in erosional subduction zones. On 16 June 2002 a magnitude Mw=6.4 earthquake and its aftershocks may have nucleated at the subduction thrust to be penetrated and sampled by CRISP, ~40 km west of Osa Peninsula.
Global event locations present uncertainties too large to prove that the event actually occurred at a location and depth reachable by riser drilling. We have compiled a database including foreshocks, the main shock, and ~400 aftershocks, with phase arrival times from all the seismological networks that recorded the 2002 Osa sequence locally. This includes a temporal network of ocean-bottom hydrophones (OBH) that happened to be installed close to the area at the time of the earthquake. The coverage increase provided by the OBH network allow us to better constrain the event relocations, and to further analyze the seismicity in the vicinity of Osa for the six months during which they were deployed. We derived a minimum 1D model and used probabilistic earthquake relocation. Moreover, we undertook teleseismic waveform inversion to provide additional constraints for the centroid depth of the 2002 Osa earthquake. The latter, together with the maximum likelihood hypocenter, places the main shock origin at 5 to 10 km depth, ~30 km landward from the trench.
Along the Costa Rican seismogenic zone, the 2002 Osa sequence is the most recent. It nucleated in the SE region of the forearc where this erosional margin is underthrust by a seamount covered ocean plate. A Mw=6.9 earthquake sequence occurred in 1999, co-located with a subducted ridge and associated seamounts. The Osa mainshock and first hours of aftershocks began in the CRISP area, ~30 km seaward of the 1999 sequence. In the following two weeks, subsequent aftershocks migrated into the 1999 aftershock area and also clustered in an area updip from it. The Osa updip seismicity apparently occurred where interplate temperatures are ~100°C or less.
In this study, we present the relocation of the 2002 Osa earthquake sequence and background seismicity using different techniques and a moment tensor inversion for the mainshock, and discuss the corresponding uncertainties, in an effort to provide further evidence that the planned Phase B of CRISP will be successful in drilling the seismogenic coupling zone.

Repeated brittle deformation under blueschist- to subgreenschist-facies conditions during exhumation of subducted oceanic crust (Bantimala Complex, Sulawesi)

Baese R, Schenk V

SFB 574 „Volatiles and fluids in subduction zones“, Christian Albrechts Universität Kiel, D-24118 Kiel

The Bantimala Complex of SW Sulawesi (Indonesia) exposes HP and UHP metamorphic rocks, which derive from a subduction zone that was active during the Cretaceous. During this time the oceanic crust of the Ceno-Tethys was subducted beneath the Sundaland continent in the north (Metcalfe, 1994, Parkinson et al. 1998). The complex is composed of tectonic slices that are interlayered and composed of either sediments (e.g. cherts) or metamorphic rocks (blueschists, eclogites, micaschists). Different metamorphic processes can be studied in these rocks as the prograde

blueschist-eclogite transformation during subduction of the oceanic crust and the fluid-rock interaction processes that took place during uplift and retrogression.
The aim of this study is to unravel the formation of different kinds of breccias, which show evidence of brittle deformation during uplift. The deformation started at eclogite-facies conditions but continued through the blueschist and greenschist facies to the subgreenschist facies. Brecciated eclogites with rehydrated glaucophane-bearing material in the matrix between the clasts indicate a brittle deformation phase during uplift from eclogite-facies to blueschist-facies conditions. Similarly, blueschist clasts in a blueschist matrix, blueschist clasts in a greenschist matrix, greenschist clasts in greenschist matrix and subgreenschist clasts in a subgreenschist matrix indicate a repeated brittle deformation during exhumation.
Thermobarometric calculations show that different blueschist and eclogite samples derive from different subduction depths within the slab. In addition, because some of the samples were formed under similar pressure conditions (2.6-2.7 GPa) but varying peak temperatures ($\Delta T=150°C$) and assuming that these rocks were formed during the same subduction process at nearly the same time, they seem to derive from different depths (original vertical) within the lithospheric slab. The breccias of the mafic rocks of the Bantimala Complex reflect an exhumation process that led to imbrication of different slices of the subducted slab.
The formation of the breccias during uplift and retrogression of the slab rocks and the observation of the displacement of the former stratigraphy within the slab argues for an exhumation of the HP/UHP rocks during compression. The HP/UHP rocks are not embedded and therefore were not carried by a low viscosity and low density matrix (e.g. serpentinite). Therefore, exhumation was driven by intra-slab shearing and upward directed motion of single slices. This kind of exhumation is similar to that described by Angiboust et al. (2012) for ophiolites of the western Alps. As in the case of the Bantimala Complex even UHP rocks were exhumed, it becomes evident that this exhumation mechanism is effective even at great depth.

References

Metcalfe, I. (1994). J. of South American Earth Science. 7, 33-347.
Parkinson,C.D., Miyazaki, K., Wakita, K., Barber, A.J. and Carlswell, D.A. (1998). The Island Arc. 7, 184-200.
Angiboust, S., Langdon, R., Agard, P., Waters, D. and Chopin, C. (2012). J. metamorphic Geol.. 30, 37-61.

Resolving deep-crustal magma reservoirs beneath the South Chilean and Nicaraguan volcanic arcs with magnetotelluric soundings

Heinrich Brasse

Freie Universität Berlin, Email: heinrich.brasse@fu-berlin.de

Magnetotelluric experiments were conducted in various regions of the South and Central American subduction zones: 1) Central Andes of Chile, Bolivia and Argentina, 2) Southern Andes in Chile and 3) Costa Rica and Nicaragua. They all aimed at the resolution of fluid/melt occurrences and reservoirs from the plate interface, asthenospheric wedge and possibly magma chambers beneath the volcanic arcs.
Two-dimensional modeling of Costa Rica data on a profile extending from Nicoya peninsula via Tenorio volcano towards the backarc did not reveal any significant conductive structure beneath the arc. In contrast, a mid-crustal conductor – indicative for a large magma reservoir – is present beneath Western Nicaragua, i.e. Momotombo volcano. This conductor could only be resolved by 3-D inversion.
A similar feature was modeled – again with the help of 3-D inversion – under the Lazufre complex in the Central Andes, which is characterized by large-scale deformation with an inflation rate of currently 3 cm/a as deduced from InSAR data. Obviously this inflation is caused by influx of magmatic material into the upper crust. The situation is far less clear in Southern Chile where a series of crustal conductors is apparently not located directly beneath the volcanic arc but rather slightly offset. This holds for all 3 transects across Lonquimay, Llaima and Villarrica. An interesting observation in S. Chile is the deflection of induction vectors in the forearc which can until now only be explained with an anisotropic layer in the mid-crust, reflecting a pattern of deep-reaching, fluid-filled fractures due to oblique subduction of the Nazca plate. A common structure of all transects in all study areas evaluated so far is a lower crustal conductor in the forearc, imaging fluids from the downgoing plate and located usually several tens of kilometers in front of the volcanic line.

Along-arc variations in magma chamber depth of large explosive eruptions in Central America: constraints from fluid inclusions and mineralogy

Burkert C, Hansteen TH, Freundt A, Kutterolf S

SFB 574, GEOMAR Helmholtz Centre for Ocean Research, Wischhofstr. 1-3, 24148 Kiel, Germany

We have applied a combination of fluid inclusion and amphibole thermobarometry to felsic tephras from highly explosive volcanic eruptions along the Central American volcanic arc (CAVA) from Guatemala through Nicaragua in order to constrain pre-eruptive magma ascent and storage conditions. We note that this is the first time a combination of pressure estimates from fluid inclusions and amphibole chemistry have been used to quantify multi-stage magma chamber processes and magma ascent velocities of large eruptions.
Our data document a stepwise ascent of magmas through the crust, typically involving at least two levels of stagnation. Amphibole and fluid inclusion thermobarometry both indicate a shallow pre-eruptive magma storage level at 80 to 200 MPa (3-8 km depth) along the entire arc. The deeper levels of magma storage vary along-arc, with a tendency to greater maximum depths of up to 25 km in Guatemala and El Salvador, compared to maximum depths of 15 km in Nicaragua. We assume that the continental crust of about 45 km thickness in Guatemala, compared to the 30km thickness of the largely oceanic crust of Nicaragua, allowed for deeper positions of the magma chambers. Thus the observed along-arc changes in mid-crustal magma storage depths indicate a dependence between magma chamber formation and the composition and probably density of the local crust.
The average composition of the pre-eruptive fluid phase for highly explosive eruptions in Central America amounts to 90% water, 5% CO_2 and 5% NaCl equivalents, and show no systematic along-arc variations. The pressures obtained from the earliest fluid inclusions were taken as the pressures of fluid oversaturation and thus for the beginning of degassing. They range between 150 and 400 MPa, and do not show systematic along-arc variations. Such fluid oversaturation pressures correspond to water contents between 4-8 wt% in the felsic melts. Our results show that the depths of fluid saturation are mostly independent of crustal properties. Degassing typically started at pressures 150 to 300 MPa higher that those corresponding to the last stagnation level, providing evidence for the pre-eruptive criticality of the systems.

3D Double Difference Tomography of the Seismogenic Zone Beneath Costa Rica and Nicaragua

DeShon HR, CERI, University of Memphis, hdeshon@memphis.edu
Moore-Driskell MM, CERI, University of Memphis, mmdrskll@memphis.edu

The Nicaragua/Costa Rica segment of the Middle America subduction zone exhibits seismogenic zone characteristics that are strongly dependent on plate structure, temperature, and fluid-related processes. Local earthquake tomography-derived velocity models aimed at characterizing lateral and downdip variability along the megathrust have to date been limited to individual onshore/offshore experiments. This study integrates data from a quality-controlled integration of amphibious datasets from the Osa and Nicoya networks collected as part of CRSEIZE (PIs. S. Schwartz/L. Dorman) and the Jaco/Quepos, Nicaragua, and Nicaragua outer-rise networks collected as part of the SFB 574 program (PIs. E. Flueh/W. Rabbel). We use double difference tomography, combining catalog derived absolute and differential times and waveform cross-correlation derived differential times, to provide an along-strike continuous image of the seismogenic zone. The compressional velocity images appear broadly consistent with previous studies. Highest resolution occurs within the shallow seismogenic zone, but we also image the nose of the forearc mantle wedge. We find that the updip limit of seismogenic zone microseismicity is variable and may be located closer to trench in Nicaragua. The interplate interseismic microseismicity occurs near the expected continental Moho intersection with the subducting plate interface, and comparison with recent subduction tremor, which occurs downdip of microseismicity, suggests that the tremor may be a better proxy for the downdip limit of rupture during major earthquakes. Results provide insight into the role of fluids within the seismogenic zone and shallow forearc mantle.

Neogene evolution of the Northern Patagonian Andes: arc development and associated deformational stages (36-43ºS)

A. Folguera, E. Rojas Vera, D. Orts, M. Spagnuolo, L. Sagripanti, J. Tobal, M. Ramos, V.A. Ramos

Email: andresfolguera2@yahoo.com.ar
Instituto de Estudios Andinos. Universidad de Buenos Aires.

During the last years increasing evidence and discussion about the role of shallow and flat subduction settings in the construction and destruction of the Andes and North American cordillera have emerged. These models have at a certain extent explained the pattern of magmatic variability through time as a product of changes in the angle of subduction. These subduction geometry variations are thought to have triggered heat flux changes, associated with injection and extrusion of important volumes of asthenospheric material, potentially accompanied by thermal and mechanical removal of the lower lithosphere. Deformational stages would have also been linked to these processes and associated with the upraise of fragile/ductile transitions at the middle crust in the retroarc zone as arc expanded landwards, as well as with lower crust delamination.

The Northern Patagonian Andes have been built through these processes. A first important shortening took place in Late Cretaceous at the time of eastward arc expansion potentially linked to three areas of subducted slab shallowings of 200 and 800 km wide respectively. One of these shallowings has evolved to one smaller flat slab in Eocene times, while the others have steepened prematurely in Paleocene times. During Late Oligocene times a broad area of steepening developed with the emplacement of voluminous basaltic and rhyolitic plateaux in central Patagonia and extensional basins in the hinterland zone. Lately three Miocene shallow subduction settings more than 400 km long each, evidenced by arc expansions and associated with Andean uplift occurred partially superimposed to the previous shallow configurations.

The Northern Patagonian Andes have been constructed through multiple mechanisms that range from i) primary contractional structures detached from fragile/ductile transitions when the arc expanded towards the foreland and consequently the crustal thermal structure changed to ii) tectonic inversion of peri-Gondwanic Mesozoic and Oligocene extensional structures when no arc migration existed and the crust yielded through previous anisotropies. These two mechanisms have acted during two distinctive orogenic stages, first at the base of Late Cretaceous and lately in Miocene times. Late Oligocene extension separates these two constructional periods and is recorded by half-grabens developed from the arc to the retroarc region. The last constructional stage (late Early to Late Miocene) was maximum where arc expanded, particularly at 34.5º-38ºS and 41º-43.5ºS. As a consequence of this, two foreland basins have developed since 18 Ma that have been subsequently cannibalized exposing their remnants in the hinterland zone. Blind and emergent structures formed a broken foreland at the frontal zone inferred from growth strata geometries.

These Neogene shallow subduction zones determined most of the Present morphological characteristics of the Southern Andes, as well as controlled magmatic mechanisms associated with their final steepening. Then these areas were extensionally/transtensionally reactivated in the last 5 My at the time of retraction and steepening of formerly shallow subduction zones, being associated with voluminous mantle derived materials and shallow asthenospheric injection, evidenced by S wave tomographies, resistivity surveys, receiver function analyses, geoid anomalies, anomalous heat flux determined from magnetic data and important volumes of within-plate foreland eruptions and minor synextensional silicic collapse calderas in the hinterland zone.

Even though Pliocene to Quaternary times at the retroarc area are dominated by extensional processes associated with within-plate volcanic activity, more locally, seismic refraction data and gravimetric models revealed a shallower sector of the Nazca plate at 37ºS in the order of 8º respect to neighbor sectors. This shallower setting coincides with the collision of the Mocha oceanic plateau, formed by highly serpentinized oceanic rocks sheared at the Mocha fracture zone. This plateau has collided against the Chilean trench between 36º and 39ºS in the last 4 Ma producing mountain building processes that acted initially at the Chilean coast, revealed by field and fission track data and propagated into the retroarc area reactivating previous Late Cretaceous structures and creating a new wave of contractional deformation. Moreover, the arc front has eastwardly migrated in this segment some 40 km indicating that slab shallowing is the cause of the renewed wave of contractional deformation at these latitudes in Late Pliocene to Quaternary times.

The extensive record of Galapagos-tracks interaction with the Central American subduction system: A natural laboratory for the evolution of continental crust.

E. Gazel[1], J. Hayes[2], K. Hoernle[3], W. Steven Holbrook[2], P. Kelemen[4], M.J. Carr[5]

[1]Deparment of Geosciences, Virginia Tech, 5041Derring Hall (0420), Blacksburg, VA 24061
[2]Department of Geology and Geophysics University of Wyoming , 1000 E. University Ave., Dept. 3006, Laramie, WY 82071
[3]IFM-GEOMAR Wischhofstr. 1-3 D-24148 Kiel, Germany.
[4]Lamont-Doherty Earth Observatory Columbia University, 61 Rt. 9W, Palisades, NY 10964.
[5]Dept. of Earth and Planetary Sciences, Rutgers University, 610 Taylor Road, Piscataway, NJ 08854-8066 U.S.A.

Although most Central American magmas have a depleted MORB-source mantle (fluxed by subduction-derived fluids), magmas in southern Central America (Costa Rica and Panama) have isotopic and trace element compositions with a Galapagos affinity. How Galapagos-influenced signature was introduced into the Central American mantle has been at the heart of the conflicting theories. Our new data collected as collaboration during the SFB 574, allowed us to produce the most complete reconstruction of the evolution of subduction system (Costa Rica, 30-0 Ma and Panama, 70-0 Ma) ever produced. We discovered that the Galapagos signature has a relatively recent origin (<10 Ma) and correlates with the interaction of geochemically enriched Galapagos tracks with the subduction system. After this dramatic change in subduction input magmas from southern Central America not only inhered an anomalous Galapagos isotopic signature but also evolved from primitive arc geochemistry to compositions closer to continental crust. Recent seismic velocity models from the TICO-CAVA active source project in Costa Rica also suggest that this island arc is the closest to continental crust. The evolution of the arc into a continental land-mass culminated in the formation land bridge that allowed exchange of fauna between the Americas and changed global oceanic circulation and climate. Finally, the evolution towards a continental character makes this a unique location a natural laboratory to test different models of continental evolution in the early Earth.

Segmentation of the 1960 Great Chile (Mw 9.5) and the 2010 Maule (Mw 8.8) earthquakes controlled by a giant submarine slope failure

Geersen J [1*], Völker D [1], Behrmann J [1,2], Weinrebe W [1,2], Kläschen D [2], Krastel S [2], Reichert C [3]

[1] Collaborative Research Centre (SFB) 574
* now at National Oceanography Centre Southampton
[2] Helmholtz-Zentrum für Ozeanforschung Kiel | GEOMAR
[3] Bundesanstalt für Geowissenschaften and Rohstoffe (BGR)

About 1000 km of the South Chilean margin were ruptured in 1960 by the Mw 9.5 Great Chile Earthquake. Early in 2010 the immediate area to the north was affected by the Mw 8.8 Maule Earthquake. In the area of the rupture boundary three giant Pleistocene submarine slope failures are observed in bathymetric and reflection seismic data. The slope failures each shifted volumes between 253 km³ and 472 km³ of slope sediments, compacted accretionary wedge material and continental framework rock from the continental slope into the trench. Seismic reflection data image an undisturbed well layered sedimentary trench fill and a continuous décollement in the areas where no slope failures are observed. However, at the exact locations of the slope failures, which coincide with the boundaries of the 1960 and 2010 ruptures, chaotic slide deposits compose the lower part of the trench-fill. At these locations no continuous décollement has developed. We speculate that the underthrusting of the highly inhomogeneous slide deposits prevents the development of a continuous décollement and thus the buildup of a thin (few millimeters) slip zone that is continuous in space as necessary for earthquake rupture propagation. Thus the 1960 Great Chile – 2010 Maule earthquake rupture boundary seems to be controlled by the underthrusting of products of giant submarine slope failures which impeded further propagation of earthquake rupture during both events. Our results emphasize that upper plate mass wasting, if it impacts on the internal structure and composition of the subduction channel rocks, can play a key role in defining seismotectonic segmentation at convergent plate boundaries.

Post-glacial time series of explosive eruptions and associated changes in the magma plumbing system of Lonquimay Volcano, South Central Chile

Gilbert D, Freundt A, Kutterolf S, Burkert C
SFB 574, GEOMAR, Wischhofstr. 1-3, 24148 Kiel, Germany

The Lonquimay Volcanic Complex (LVC) in the high Southern Andes comprises a stratocone and NE-trending flank-cone alignments. Numerous effusive and explosive volcanic eruptions characterize its post-glacial magmatic activity. Our tephrostratigraphic record, pre-dating the four historically documented eruptions, comprises 22 dated pyroclastic deposits that are used to constrain repose time distribution and eruption probability of the LVC magmatic system. Statistical examination of the stratigraphy-based eruption time series yields probabilities of 20-50% for at least one explosive (VEI≥3) eruption within the next 100 years as of 2011.
The tephra deposits are subdivided into three petrographic groups: a felsic group (Lonquimay Colored Pumice Tephra, LCPT), an intermediate population (Lonquimay Grey Pumice Tephra, LGPT) and a mafic member (Lonquimay Dark Scoria Tephra, LDST). The distribution of these petrographic groups through the LVC tephrostratigraphy is linked to the observed changes in repose times. LDST deposits as well as deposits compositionally zoned from LCPT to LGPT dominate the lower part of the stratigraphy for which recurrence times are short (RT_{mean}=417±169a). Deposits younger than 6000 b2k (years before 2000 AD) have dominantly LCPT and minor LDST compositions, no longer contain LGPT, and repose times are significantly longer (RT_{mean}=1350±310a). We interpret the change in eruption regime to result from a rearrangement in the magma storage and plumbing system. Thermobarometric calculations based on cpx liquid equilibria and amphibole compositions reveal three distinct magma storage levels: the mafic LDST derive from mid crustal storage (P_{mean}= 476±95 MPa, T_{mean}=1073±24°C), felsic LCPT mainly erupted from upper-crustal level (P_{mean}= 86±49 MPa , T_{mean}=936±24°C), whereas LGPT samples yield intermediate storage depths (P_{mean}= 239±100 MPa, T_{mean}=1013±17°C). Magma contributions from this intermediate reservoir are restricted to >6000 b2k when the Lonquimay plumbing system was in a regime of short repose times; disappearance of the intermediate reservoir coincides with the change to longer repose times between eruptions.

Magmatic evolution and volatile inventory of the Lonquimay Volcano, South Central Chile

Gilbert D, Freundt A, Kutterolf S, Burkert C, Garbe-Schönberg D

SFB 574 at GEOMAR, Kiel, Germany, dgilbert@geomar.de

The Lonquimay Volcanic Complex (LVC) in South Central Chile (38.38°S, 71.58°W) is part of the Southern Volcanic Zone of the Andes, which formed in response to the subduction of the Nazca Plate beneath the South American Plate. During the last 10200+-70 years of its magmatic evolution, the LVC produced 23 explosive eruptions documented in the succession of widespread tephra deposits. We investigated this stratigraphic sequence for matrix glass, mineral and bulk rock compositions of the juvenile components. Furthermore, melt inclusions were analyzed for their major element and volatile contents. The tephra succession reflects six mafic replenishments of the LVC magma reservoir followed by progressive magmatic differentiation. Each cycle has been successively tapped by several eruptions. Compositionally zoned tephras were typically deposited early in a cycle, whereas late eruptions discharged more evolved magmas. Intermediate compositions typically contain mixed disequilibrium mineral assemblages. The maximum degree of fractionation reached during a cycle increases with younger ages. Our investigations of melt inclusions, in order to reconstruct the pre-eruptive volatile inventories of the LVC magma chamber, reveal the exsolution of two separate fluid phases. One S-rich fluid phase released from mafic melts in the middle crust and one Cl-rich aqueous phase, released from more differentiated melts that resided in the upper part of LVC´s plumbing system. The pre-eruptive saturation state of the LVC melts indicates that felsic eruptions may have been triggered by H_2O-supersaturation whereas mafic melts seem to have experienced a complex replenishment history potentially exciting LVC´s mafic eruptions.

Arc magma geochemistry accompanying collision: Molucca Sea, Indonesia, and West Bismarck arc, Papua New Guinea

James Gill (UCSC), Takeshi Hanyu (JAMSTEC), Heather Cunningham and Simon Turner (Macquarie)

The Sangihe arc, Indonesia, and the New Britain arc, PNG, have slab thermal parameters within the range of most oceanic arcs. However, the Sangihe arc is involved in an arc-arc collision, and the New Britain arc in an arc-continent collision. Both collisions have commenced on one end and are progressing to the other. The non-collisional end of both arcs has across-strike variations in trace element and isotope ratios similar to those of the Izu arc, that are interpreted as reflecting more enriched mantle and a higher-T slab component in the backarc, progressive dehydration of the slab, and the temperature-dependence of accessory minerals in the slab. The slab component appears to be mostly from the subducting basaltic crust even though the overlying sediment layer reaches 10 km beneath the Molucca Sea. Collision is most advanced in the West Bismarck arc of PNG. There, a second sediment-derived component has been added to the magmas, apparently in the lower crust affected by underplating of subducting sediment. U-series data show that the time scale of arc magma genesis is unaffected by collision but that the addition of crustal melts reduces U-Th fractionation. In the northern Sangihe arc, volcanism migrated toward the backarc as collision began, but magmas remained similar to those of the backarc elsewhere. Therefore, the geochemistry of arc magmas is largely unaffected by impending collision, but may acquire an anatectic crustal melt overprint once active subduction stops.

MEDACOR - an aero-geophysical offspring of the SFB 574 in Costa Rica

Götze HJ, Christian-Albrecht Universität, and MEDACOR partners

The German – Costa Rican MEDACOR research group (MEDACOR stands for: Mediciones Aerogravimetricas en Costa Rica) will conduct an airborne gravimetry and magnetic campaign in Costa Rica in Central America, which will result in a modern, homogeneous database for the territory of this country. Instead of ground measurements, an airborne campaign is necessary due to extended coverage of the Costa Rican territory with tropical jungle. It will be conducted between February and March 2013, set up by a workshop on integrated modelling and interpretations in summer 2012. The project aims to acquire new, modern gravity and magnetic field databases for use in 3-D modelling to determine densities, lithospheric rigidity, topography of discontinuities, and stress calculations in the upper/lower crust and the upper mantle under the Central American land bridge and adjacent areas. The mapping of the subduction and surface near crust geometry (shape, depth, width, lineaments) and the gravity related parameters (density, rigidity, stress, gravity potential energy - GPE) of Central America will provide constraints for modelling the dynamics of hazardous fault zones and volcanic risks in this area. These results have to be combined with the findings from local seismicity, and electromagnetic (data bases of UCR and ICE), magnetic, geology, petrology and neo-tectonic studies in an integrative interpretation and later also dynamic modelling.

PIs of the MEDACOR project:
Hans-Jürgen Götze (leading), Institut für Geowissenschaften, Abt. Geophysik, Christian-Albrechts-Universität zu Kiel, CAU
Christoph Förste, Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences Potsdam
Uwe Meyer, Bundesanstalt für Geowissenschaften und Rohstoffe, BGR, Hannover
Eduardo Sibaja Arias, Allan Campos, Cornelia Miller, Gustavo Otárola, Centro Nacional de Alta Tecnología, CeNat, San Jose
Guillermo Alvarado and Mauricio Mora, Universidad de Costa Rica, UCR, San Jose
Steven Kenyon, National Geodetic Agency, USA

Bending-related faulting and mantle serpentinization at deep-sea trenches

Ingo Grevemeyer

SFB 574, GEOMAR | Helmholtz Zentrum für Ozeanforschung Kiel, Wischhofstraße 1-3, D-24148 Kiel

The understanding of the Earth's water cycle is inherently linked to the subduction of water at deep sea trenches. The transfer of water into the deep Earth's interior is related to the alteration and hydration of the incoming lithosphere. The release of water from subducting lithospheres affects the composition of the mantle wedge, enhances partial melting and triggers intermediate-depth earthquakes. Water is transferred with the incoming plate into the subduction zone as water trapped in sediments and open void spaces in the igneous crust and as chemically bound water in hydrous minerals in sediments and oceanic crust (Jarrad, 2003). However, if water reaches upper mantle rocks, significant amounts can be transferred into the deep subduction zone as water-bearing mineral serpentine (Peacock, 2004). Serpentinites have nearly the same chemical composition as mantle peridotite except that they contain approximately 13 wt% water in mineral structures.
Seismic refraction and wide-angle data were collected at a number of active continental margins in the trench-outer rise to investigate the impact of bending related normal faulting on the seismic properties of the oceanic lithosphere prior to subduction. Surveys provided data from offshore of Nicaragua (Grevemeyer et al., 2007; Ivandic et al., 2008), Chile (Contreras-Reyes et al., 2008), and Tonga (Contreras-Reyes et al., 2011). At all settings tomographic joint inversion of seismic refraction and wide-angle reflection data yielded anomalously low seismic P-wave velocities in the crust and uppermost mantle seaward of the trench axis. Crustal velocities are reduced by 0.2-0.8 km/s compared to normal mature oceanic crust. Seismic velocities of the uppermost mantle are 7.4-7.8 km/s and hence 5-12% lower than the typical velocity of mantle peridotite. These systematic changes in P-wave velocity from the outer rise towards the trench axis indicate an evolutionary process in the subducting slab consistent with percolation of seawater through the faulted and fractured lithosphere and serpentinization of mantle peridotites. The observed velocity reduction suggests that mantle serpentinization reaches 12-25%. Thus, processes occurring in the trench-outer rise affect indeed the Earth's water cycle and indicate that significant amount of waters are transferred into the subducting lithosphere and hence carried to the deep Earth interior.

References

Contreras-Reyes, E., Grevemeyer, I., Flueh, E.R., and Reichert, C. (2008), Upper lithospheric structure of the subduction zone offshore of southern Arauco peninsula, Chile, at 38°S, J. Geophys. Res., 113, B07303, doi:10.1029/2007JB005569.
Contreras‐Reyes, E., Grevemeyer, I., Watts, A.B., Flueh, E.R., Peirce, C., Moeller, S., and Papenberg, C., 2011. Deep seismic structure of the Tonga subduction zone: Implications for mantle hydration, tectonic erosion, and arc magmatism, J. Geophys. Res., 116, doi:10.1029/2011JB008434.
Grevemeyer, I., Ranero, C.R., Flueh, E., Kläschen, D., Bialas, J. (2007). Passive and active seismological study of bending-related faulting and mantle serpentinization at the Middle America trench. Earth Planet. Sci. Lett. 258, 528-542.
Ivandic, M., Grevemeyer, I., Berhorst, A., Flueh, E.R. and McIntosh, K. (2008), Impact of bending related faulting on the seismic properties of the incoming oceanic plate offshore of Nicaragua, J. Geophys. Res., 113, B05410, doi:10.1029/2007JB005291.
Jarrad, R.D. (2003). Subduction fluxes of water, carbon dioxid, chlorine, and potassium. Geochemistry, Geophysics, Geosystems 4: doi: 10.1029/2002GC000392.
Peacock, S.M. (2004). Insight into the hydrogeology and alteration of oceanic lithosphere based on subduction zones and arc volcanisms. In: Davis E.E, Elderfield, H. (Eds.), Hydrogeology of Oceanic Lithosphere. Cambridge University Press, pp. 659-676.

Nitrogen recycling in subduction zones

Ralf Halama

SFB 574, Institute of Geosciences, University of Kiel, 24098 Kiel, Germany

Nitrogen (N) is the seventh most abundant element in the universe and accounts for ~78 vol.% of the Earth's atmosphere. Knowledge of the amount of N being subducted and the extent to which N is released from subducting rocks during devolatilization is of fundamental importance in understanding Earth's nitrogen cycle. Estimates of the amounts and isotopic compositions of subducted N are critical in evaluating whether or not the N isotope compositions of certain mantle-derived magmas reflect retention of N in deeply subducted oceanic lithosphere and sediments [1, 2]. It is also critical in attempts to balance subduction zone N inputs from the subducting plate with N outputs in arc volcanic gases [3, 4]. For N, the presence of a significant imbalance between a large, isotopically heavy

subducted flux compared to an isotopically light, relatively small outgassed flux suggests that significant amounts of N were trapped in the mantle during Earth's history [5].
Nitrogen concentrations and isotopic compositions of high- and ultrahigh-pressure mafic eclogites, aimed at characterizing the subduction input flux of N in deeply subducting oceanic crust, show positive $\delta^{15}N$ values and elevated N contents, which are distinct from fresh MORB but overlap with altered oceanic crust [6]. The N systematics indicate negligible effects of metamorphic devolatilization, but some eclogite suites show evidence for fluid-mediated addition of a sedimentary N component.
Concentrations and isotopic compositions of N in hydrated mantle rocks were determined in samples reflecting different stages of the subduction zone cycle, from oceanic alteration to high-pressure metamorphism, to assess redistribution and isotope fractionation of N by ultramafic dehydration and to determine the magnitude of N subduction in hydrated slab mantle. Low-grade serpentinized peridotites that formed during early stages of subduction have variable $\delta^{15}N$ values, ranging from values close to the composition of the depleted mantle (-5‰) to isotopically heavier values overlapping those of modern marine sediments and metamorphosed sedimentary rocks. This suggests an addition of organic-sedimentary N to the peridotites, incorporated via serpentinization during bending–related faulting of the slab and/or via metasomatic additions during hydration in the forearc mantle wedge. Nitrogen is retained in HP peridotites down to depths of at least 60-70 km, and there is apparently no significant loss of N due to dehydration. Hence, the sedimentary N isotopic signature, derived from interaction with serpentinizing fluids, is largely preserved during prograde dehydration of the slab mantle.
Calculated global input fluxes for a range of representative subducting sections of unmetamorphosed and HP-metamorphosed slabs, all incorporating serpentinized slab mantle, range from 1.1×10^{10} to 3.9×10^{10} mol N_2/year. The best estimate for the $\delta^{15}N_{air}$ of the subducting slab is +4±1‰, supporting models that invoke recycling of subducted N in mantle plumes and consistent with general models for the volatile evolution on Earth.
References: [1] Marty and Dauphas, 2003, EPSL 206:397-410; [2] Jia et al., 2003, EPSL 215:43-56; [3] Li et al., 2007, GCA 71:2344-2360; [4] Mitchell et al., 2010, G3 11:Q02X11, doi:10.1029/2009GC002783; [5] Javoy, 1998, Chem. Geol. 147:11-25; [6] Halama et al., 2010, GCA 74:1636-1652

Magmatic signatures and metasomatism in the high-pressure metamorphic Raspas Complex, Ecuador

Halama R [1], John T [2], Herms P [1], Schenk V [1], Garbe-Schönberg D [1], Hauff F [3]

[1] SFB 574 and Institute of Geosciences, University of Kiel, 24098 Kiel, Germany
[2] Institute for Mineralogy, University of Münster, 48149 Münster, Germany
[3] SFB 574 and GEOMAR, 24148 Kiel, Germany

The Raspas Complex is a high-pressure (HP) metamorphic complex in southwest Ecuador, representing an exhumed fragment of oceanic lithosphere. It is one of the few high-pressure ophiolites that contain the whole lithological sequence of a typical subducting slab and is therefore ideally suited to investigate how the different parts of the slab and their element budgets behave during subduction. The complex is subdivided into the Raspas Formation, which comprises eclogites, blueschists and metasediments, and the El Toro Formation, which consists of eclogite-facies, serpentinized peridotites [1]. Peak P-T conditions for eclogites and garnet-chloritoid-kyanite metapelites are very similar at about 2 GPa and 550-600 °C, and the age of metamorphism is around 130 Ma [2, 3].
Two distinct types of eclogites can be distinguished based on petrography and trace element geochemistry. The first eclogite type has a geochemical signature similar to mid-ocean ridge basalts (MORB) [3, 4], whereas the second eclogite type is characterized by the presence of zoisite and the relative enrichment in many incompatible trace elements (e.g. Th, U, Pb, LREE). Stable (Li, O) and radiogenic (Sr, Nd) isotopic compositions of the eclogites are used to constrain the effects of fluid-induced metasomatism in metabasaltic rocks at HP conditions and to identify fluid sources. For the MORB-type eclogites, Sr and O isotopic compositional differences on outcrop scale and Sr-Nd isotopic trends typical for seafloor alteration suggest inheritance from variably altered oceanic crust [5]. Lithium isotope compositions point to Li isotopic fractionation by diffusion-related fluid-rock interaction, demonstrating the high sensitivity of the Li isotope system to metasomatic effects. The

zoisite eclogites are thought to have formed by a fluid-induced high-pressure metasomatic overprint, and their Sr-Nd isotopic compositions indicate a metasedimentary fluid component [5].
Within the serpentinized ultramafic rocks, which show evidence for prograde HP dehydration, metamorphosed dikes contain pargasitic amphibole, vesuvianite and rare Ca-rich garnet. Although the primary magmatic mineral assemblage has been replaced, elevated Al_2O_3 and CaO contents and correlations between Ni and MgO are similar to pyroxenites from orogenic ultramafic massifs. Positive Eu anomalies and up to 10× chondritic REE abundances point towards an origin as plagioclase-bearing ultramafic cumulates based on similarities to cumulate gabbros and plagioclase wehrlites from abyssal plateaus and ultramafic massifs [6].
References:
[1] Feininger, T. (1980): J. Petrol. 21:107-140. [2] Gabriele, P. et al. (2003): Eur. J. Mineral. 15:977-989. [3] John, T. et al. (2010): Contrib. Mineral. Petrol. 159:265-284. [4] Halama, R. et al. (2010): Geochim. Cosmochim. Acta 74:1636-1652. [5] Halama, R. et al. (2011): Chem. Geol. 281:151-166. [6] Borghini, G. et al. (2007): Lithos 94:210-229.

Strong variations in degassing rates at Villarrica Volcano (Southern Chile): Consequences for deep-seated processes

T. H. Hansteen (1), S. Bredemeyer (1), C. Mora Stock (2), Y. Dzierma (2), M. Thorwart, W. Rabbel (2), K. Garofalo (1), F. Gil Cruz (3)

(1) SFB 574, GEOMAR, Wischhofstrasse 1-3, 24148 Kiel, Germany
(2) SFB 574, Institute of Earth Sciences, University of Kiel, Germany
(3) OVDAS-SERNAGEOMIN, Dinamarca 69, Temuco, Chile

Villarrica is one of the most active volcanoes in Chile, has a persistent lava lake within its crater, and is presently characterized by continuous degassing and high-level seismicity. We use a multiparameter approach based on high time-resolution gas flux measurements and seismic data to characterize magmatic and tectonic processes controlling the volcanic activity. The instrumentation includes 3 ground-based NOVAC-type scanning Mini-DOAS spectrometers for the quantification of SO_2 fluxes, installed at the volcano in March 2009, which are complemented with seismic data from the catalogue of the Volcanic Observatory of the Southern Andes (OVDAS in Spanish) and from the SFB 574 temporary volcanic network.
During the last three years, we have detected activity variations at Villarrica occurring on several time scales, which can be related to distinct processes at depth.
The monthly averages in degassing rates increased from 400 tons/d SO_2 before December 2009, to about 1200 tons/d SO_2 in April 2010. Superimposed on this pattern are strong pulses of seismic LP events occurring every 3 to 4 months, accompanied by peaks in degassing rates, interpreted as periodic influx of fresh magma batches to the deeper levels of the plumbing system. The degassing rates further show cyclic variations with a periodicity of 5 to 7 days. We interpret the latter variations to represent the turnover time for a conduit convection cycle of magma from a mid-crustal reservoir, where the degassing peaks correspond to the arrival of comparatively undegassed magma at shallow levels. In addition, irregular regional earthquake events are typically followed by increased degassing activity at Villarrica 2-4 days later, interpreted as due to increased bubble nucleation in the magmatic system at depth.
The period of strongly increasing degassing rates between December 2009 and April 2010 encompasses the M 8.8 Maule earthquake, which occurred on February 27, 2010. However, the degassing variations show a complex pattern, including a steady increase already 3 months before the Maule earthquake. Degassing rates dropped off sharply 7 days before the earthquake, and was followed by several weeks of comparatively low degassing during the aftershock phase. At the end of March, degassing rates picked up to a factor of 3 above the pre-earthquake level culminating with a peak of 2800 tons/d SO_2 at the beginning of April. The persistence of high degassing rates even two years later indicates a permanent change in the magma plumbing system. Further, the observation that the Maule earthquake rather interrupted than enhanced the trend of increased degassing requires a fundamental increase in the magma supply to Villarrica commencing months before the rupture event. We tentatively assign the increased availability of magma to pre-rupture creep in the lower crust or at mantle depths, enabling a pressure gradient for influx of magma. We suggest that such a change in the volume of incoming magma would probably have led to an eruptive cycle at a closed vent system like e.g. the neighboring Llaima volcano.

Geochemistry of (forearc) fluids

Christian Hensen

SFB 574, GEOMAR | Helmholtz Zentrum für Ozeanforschung Kiel, Wischhofstraße 1-3, D-24148 Kiel

Emanation of fluids at cold seeps, mud volcanoes, and other types of submarine seepage structures is a typical phenomenon occurring at continental margins worldwide. Cold seeps represent pathways along which volatiles and solutes are sometimes recycled from deeply buried sediments into the global ocean, and hence they may be considered as a potentially important link in global geochemical cycles. In forearcs of active margins they may help to further our understanding of exchange processes, and hence the coupling between subducting and overriding plate.
Over the past decade SFB 574 has undertaken considerable efforts to study the Central American and the Chilean forearcs as well as other areas of interest such as the Gulf of Cadiz, the Mediterranean Ridge, or the active margin off New Zealand. The results have helped to understand and systemize processes of fluid formation and alteration in different geological and tectonic environments. In this contribution we will summarize findings from the major working areas and show how these relate to forearcs of other subduction zones and seepage areas. In general, clay-mineral dewatering plays a central role in terms of fluid-mobilization from greater depth, however, resulting cold seep fluids are typically very different from each other and cover a large range of geochemical signatures. This is mainly due to variations in control parameters such as the type of sediment input or thickness of the sediment cover, thermal conditions, distribution of fluid pathways, and the potential of secondary overprinting. For example, freshened fluids emanating at cold seeps off Costa Rica indicate dewatering and related geochemical reactions in subducting sediments, while fluids sampled at mud volcanoes in the Gulf of Cadiz indicate a fluid source originating in the underlying oceanic basement and as such a hydrological connection between buried oceanic crust and the water column at high crustal ages. The latter finding is a clear spin-off of the work conducted within SFB 574 and illustrates a challenging new perspective on future cold seep research.

Gain and loss of volatile and fluid-mobile elements in subduction zones: a combined field-based and experimental approach

Astrid Holzheid

SFB 574, Institut für Geowissenschaften, Universität Kiel

Understanding the exchange of volatiles between mantle, crust and atmosphere represents a central issue of terrestrial geodynamics. Studies of uplifted tracts of subduction related metamorphic rocks can provide detailed information regarding the extent of loss of volatile and fluid-mobile elements during prograde metamorphism. Studies within SFB 574 have shown that in many cases fluid flow is channelized rather than penetrative. The study of vein systems and metasomatic reaction zones is therefore the key to understand fluid-related processes and mass transfer in subduction zones, as they track pathways of migrating fluids and record fluid compositions. These processes were studied in distinct parts of the subduction zones, representing (i) an accretionary wedge (e.g., Coastal Cordillera Accretionary Complex, Chile), (ii) the subduction mélange (e.g., Cyclades, Greece; Tianshan, China) and (iii) the subducted oceanic slab with serpentinized lithospheric mantle, high-pressure metamorphic oceanic crust and sediments (e.g., Raspas Complex, Ecuador; Bantimala Complex, Sulawesi; Zambesi Belt, Zambia). Case studies of all three mentioned parts of subduction zones will be presented.
Furthermore, the role and evolution of fluids released during subduction were experimentally studied. Instead of conducting single point analysis at a given P/T or single crystal analyses, to derive partitioning data, we tracked a more dynamic approach and investigated the evolution, and thus the change in the composition of basalts, gabbros and their respective fluids, when moving down along the subducting slab.

Control of reaction kinetics on mantle serpentinization and double Benioff zones

Karthik Iyer [1], Lars H. Rüpke [1,2], Ingo Grevemeyer [2] and Jason Phipps Morgan [3]

[1] The Future Ocean, GEOMAR, Wischhofstraße 1-3, D-24148 Kiel, Germany
[2] SFB-574, GEOMAR, Wischhofstraße 1-3, D-24148 Kiel, Germany
[3] Department of Earth and Atmospheric Sciences, Cornell University, Ithaca NY 14853, USA

The subduction of partially serpentinized oceanic mantle may potentially be the key geologic process leading to the regassing of Earth's mantle and also has important consequences for subduction zone processes such as element cycling, slab deformation, and intermediate-depth seismicity. Little is known about the quantity of water that is retained in the slab during mantle serpentinization. Recent studies using thermodynamical and/or experimental models of subduction zone processes have assumed that the mantle is uniformly serpentinized to a depth determined from the equilibrium stability of serpentine minerals in P-T space. This approach yields an incomplete picture of the pattern of serpentinization that may occur during bending-related faulting; an initial state that is essential for quantifying subsequent dehydration processes. In order to provide further constraints on the pattern of hydration and the amount of water trapped in the subducting mantle, we build a 2-D reactive-flow model incorporating the kinetic rate-dependence of serpentinization based on experimental results. After simulating hydration processes at the trench outer-rise, we find that the water content in serpentinized mantle strongly depends on the age of the subducting lithosphere and subduction rate, with values ranging between $1.8x10^5$ and $4.0x10^6$ kgm^{-2} reactive water uptake into the subducting mantle column. Serpentinization also results in a reduction in surface heat flux towards the trench caused by advective downflow of seawater into the reaction region. Observed heat flow reductions are larger than the reduction due to the minimum-water downflow needed for partial serpentinization, predicting that active hydrothermal vents and chemosynthetic communities should also be associated with bend-fault serpentinization. Model results agree with previous studies that the lower plane of double Benioff zones can be generated due to dehydration of serpentinized mantle at depth. The depth-dependent pattern of serpentinization including reaction kinetics predicts a separation between the two Benioff planes consistent with seismic observations.

Along- and across-arc geochemical variations in the Southern Volcanic Zone, Chile

G. Jacques[1], K. Hoernle [1,2], H. Wehrmann[1], D. Garbe-Schönberg[3], P. van den Bogaard [1, 2], F. Hauff[2], J. Mahlke[2], K. Schumann[2], I. Bindeman[4], L.E. Lara[5]

[1] Sonderforschungsbereich 574, GEOMAR, Kiel, Germany
[2] GEOMAR, Kiel, Germany
[3] Institute of Geosciences of the University of Kiel, Germany
[4] University of Oregon, Eugene, USA
[5] Servicio Nacional de Geología y Minería, Santiago, Chile

We present a new and comprehensive geochemical data set (Major and trace elements, Sr-Nd-Pb-O-Hf isotopes, as well as volatile (S, Cl, H_2O) contents from olivine melt inclusions) from young olivine-bearing volcanic rocks along the volcanic front (VF) in Chile and the back-arc (BA) in Argentina from the Southern Volcanic Zone (SVZ). Based on the geochemistry of the erupted rocks and with respect to previous studies, we divided the SVZ in four segments in which we slightly shifted two boundaries: the Northern VF (NVF; 33°-34.5° S), the Transitional VF (TVF; 34.5°-38° S) which extends further south from the TSVZ (34.5°-37° S), the Central VF (CVF; 38°-42° S) which also extends further south from the CSVZ (37°-41.5° S) and the Southern VF (SVF; 42°-46° S), here represented by Chaitén volcano only.
All VF samples show typical trace element signatures of subduction zones rocks, characterized by negative Nb and Ta anomalies and enrichment of fluid-mobile trace elements (Pb, Ba, Cs, U) on a multi-element variation diagram. BA samples overall follow the same pattern but are generally more enriched in incompatible elements, while their Pb and K peaks and Nb and Ta troughs are less pronounced.
Compared to the TVF, the CVF samples have higher fluid-mobile to fluid-immobile trace element ratios (e.g. higher Pb/Ce, U/Th, Ba/Nb, Ba/Th) and lower incompatible to less incompatible trace element ratios (e.g. lower La/Yb), suggesting peak fluid fluxes in this arc segment, associated with

highest degrees of melting. This observation is supported by melt inclusion water contents, which reach maximum values in the CVF. Cl and S, in contrast, are most enriched in the lower-degree melts in the NVF, TVF, and SVF, reflecting their incompatible behaviour, while being least abundant in the high-degree melts of the CVF.
On the Sr vs Nd isotopes diagram, the TVF almost completely overlaps the BA, while the CVF extends to higher Nd and/or Sr isotope ratios. The NVF shows an enriched signature with higher Sr isotope ratios and lower Nd isotope ratios. On Pb isotopes diagram, the TVF and the CVF fall on the radiogenic end of the positive BA array. A group of five BA samples has unusually elevated $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. The BA array intersects the South Atlantic MORB field, suggesting an EMORB type mantle wedge. The Chilean trench sediment field overlaps the VF samples almost entirely.
O isotopes from olivine provide strong support to the models. The TVF ($\partial^{18}O$ = 4.88-5.62‰) has typical subduction zones values, while the CVF ($\partial^{18}O$ = 4.53-4.96‰) has values lower than the mantle range (5.0-5.2‰), suggesting the presence of hydrothermally altered oceanic crust or/and serpentinites in the source. The NVF shows a wider range, from 4.53‰ to 6.53‰ (4.53-5.68‰ when excluding one sample). The BA shows a relative similar range than the TVF ($\partial^{18}O$ = 5.02-5.72‰).
The signature of the TVF lavas can be explained by a two components mixing of trench sediments (+/- subducted oceanic crust) with an EMORB type mantle wedge. Combined with morphological and geophysical data, the CVF shows higher fluid fluxes beneath the VF, derived from hydrothermally altered oceanic crust and serpentinites. NVF samples show lower $^{207}Pb/^{204}Pb$ and similar $\partial^{18}O$ than the TVF-CVF and cannot be explained simply by crustal assimilation. Subduction of lower crust cannot be excluded. The BA shows a progressive diminution of the slab signal while increasing distance from the arc.

Geochemical and Seismological Evidence for Forearc Crust and Mantle Removed by Forearc Subduction Erosion Entering the Mantle Wedge and the Arc Magma Source

Suzanne Mahlburg Kay

Dept. Earth. Atm. Sci., INSTOC, Cornell Univ. Ithaca, NY, 14853, USA (smk16@cornell.edul).

Forearc subduction erosion has been suggested to be a major process shaping the Andean margin from Colombia to Patagonia. Evidence for this process has largely come from the forearc, and questions remain as to how much of the removed forearc crust and mantle lithosphere reaches the arc magma source region and the wedge under the backarc, and ultimately how much is recycled into the mantle. This crustal and mantle lithosphere can potentially be tracked using both geochemical and geophysical methods as shown below in examples from the northern part of the Southern Volcanic Zone, the southernmost part of the Central Volcanic Zone and the Chilean (Pampean) flat-slab region.
Geochemical evidence for recycling of forearc crust in Neogene arc magmas has been suggested in regions where the frontal arc has migrated into the foreland, in particular in the northern part of the Southern Volcanic Zone on the southern margin of the Chilean-Pampean flat-slab where the arc front migrated ~ 35 km eastward at 19-16 Ma and another ~ 50 km at 7-4 Ma (Kay et al., 2005). A similar case for a pulse of forearc subduction erosion has been made in the southernmost Central Volcanic Zone on the northern margin of the flat-slab at 27°S to 28°S where the frontal arc migrated ~ 40-50 km from 8 to 3 Ma (Kay and Mpodozis, 2002; Goss and Kay, 2009; Kay et al., 2011). During this time, mafic adakitic andesitic magmas were erupted between the ~26 to 8 Ma Maricunga and < ~ 3 Ma Central Volcanic Zone arc fronts. The region is over the subducting Nazca slab where revised contours to the Wadati-Benioff zone from the southern PUNA seismic deployment show the slab bending eastward to form the northern boundary of the modern Chilean (Pampean) flat-slab region (Mulcahy et al., 2010; in prep). A restoration, assuming a constant 300 km frontal arc to trench gap since the early Miocene, suggests an average forearc loss of 164 km3/my/km over 6 million years (based on Goss and Kay, 2009). Geochemical evidence for subducted eroded forearc crust entering the arc magma source comes from: (1) transient steep REE patterns in arc magmas, which are not attributable to slab melting nor to any simple model with in situ garnet-bearing lower crustal residues, (2) elevated Mg, Cr and Ni contents consistent with partial melts of subducted eroded crust reacting with the mantle wedge prior to interacting with the overlying crust, (3) a marked step in isotopic enrichment in similar age mafic to silicic magmas at the time of arc migration, and (4) temporal isotopic changes in primitive basaltic magmas with near mantle $\delta^{18}O$ ratios (Goss and Kay, 2009; Kay

et al. 2011). These geochemical and isotopic features contrast with those in magmatic rocks that were erupted in the nearly stationary Neogene central Andean arc front north of 25°S, where only slow subduction erosion rates are inferred (Clift and Hartley, 2007).
An amount of forearc subduction erosion similar to that inferred for the regions just north of 28°S and south of 33°S where the frontal arc was translated some 40 to 50 km to the east can also be inferred for the intervening amagmatic Chilean (or Pampean) flat-slab region, in which the late Oligocene to Miocene arc front is currently some 260 km east of the Chile trench. Given that the current flat-slab geometry was not in place in this region, the active arc joining the Andean Central and Southern Volcanic zones would most likely be in the prominent Calingasta-Uspallata valley in Argentina, some 300 km from the trench. An intriguing and related question in this region is then the origin of the low Vp/Vs ratios (1.65-1.72) in the mantle wedge above the flat-slab, which are attributed to a combination of low Vp and high Vs (~4.75) seismic velocities (Wagner et al., 2006). Furthermore, Wagner et al (2006) argue that these low Vp/Vs ratio are best explained by the presence of orthopyroxene in the mantle wedge, and Wagner et al. (2010) suggest that this orthopyroxene can be produced by reacting silicic subducted sediments with mantle wedge peridotite. An alternative explanation is that these low Vp/Vs ratios reflect contamination of the mantle wedge by crustal and mantle lithosphere that was removed in the more than 40 km of forearc subduction erosion measured by the expected frontal arc migration in this region in the last 8-6 Ma. In analogy with the forearc subduction erosion models to the north (e.g., Goss and Kay, 2009) and south (Kay et al. 2005), much of this material would have entered the mantle wedge under the flat-slab in a major pulse of forearc subduction erosion between 8-3 Ma, which coincides with the inferred period of most rapid shallowing of the flat-slab (e.g., Kay and Mpodozis, 2002). The high Vs velocity in the mantle wedge in the flat-slab region relative to the lower values assigned in the south (Wagner et al., 2006) and the north (Calixto et al., 2011) likely reflects temperatures in the flat part of the subducting Nazca plate being too low to release a sufficient volatile flux to hydrate the overlying mantle wedge. The flat-slab geometry could also play a role in concentrating eroded forearc material in the mantle wedge under the flat part of the subducting Nazca plate.

References :

Calixto, F.J., E.A. Sandvol, S. M. Kay, D. Comte, P. M. Alvarado, B. Heit and X. Yuan (2011) Seismic anisotropy beneath the southern Puna plateau, EOS Transactions AGU 92, S44A-07.
Goss, A.R. and S.M. Kay (2009) Extreme high field strength element (HFSE) depletion and near-chondritic Nb/Ta ratios in Central Andean adakite-like lavas (~27º S ~68º W), Earth Plan. Sci. Lett. 270, 97-109.
Goss, A.R., S.M. Kay and C. Mpodozis (2011) The geochemistry of a dying continental arc: the Incapillo Caldera and Dome Complex of the southernmost Central Andean Volcanic Zone (~28 S), Contrib. Mineral. Petrol.161, 101-128.
Kay, S.M. and C. Mpodozis (2002) Magmatism as a probe to the Neogene shallowing of the Nazca plate beneath the modern Chilean flatslab, J. South Am. Earth Sci. 15, 39-59.
Kay, S.M., E. Godoy and A. Kurtz (2005) Episodic arc migration, crustal thickening, subduction erosion, and magmatism in the south-central Andes, Geol. Soc. Am. Bull. 117, 67-88.
Kay, S.M., A.R. Goss and C. Mpodozis (2011) Neogene Central Andean adakites, frontal arc migration and forearc subduction erosion at 27º-28.5ºS, Mineralogical Magazine 75, 1161.
Mulcahy, P., C. Chen, S.M. Kay, L.D. Brown, P. Alvarado, E. Sandvol, B. Heit and X. Yuan (2010) The SOUTHERN PUNA Seismic Experiment: Shape of the Subducting Nazca Plate, Areas of Concentrated Mantle and Crustal Earthquakes, and Crustal Focal Mechanisms, Eos Trans. AGU 91, T11A-2050
Wagner, L.S., S. Beck, G. Zandt and M. Ducea, (2006) Depleted lithosphere, cold, trapped asthenosphere, and frozen melt puddles above the flat slab in central Chile and Argentina, Earth Plan. Sci. Lett. 245, p. 289–301
Wagner, L.S., M.L .Anderson, J.M. Jackson, S.L. Beck and G. Zandt (2010) Seismic evidence for orthopyroxene enrichment in the continental lithosphere, Geology 36, p. 935-938.

Modelling the climate effects of explosive eruptions at the Central American Volcanic Arc for the last 200 ka

Krüger, K.[1,2], Timmreck C.[1,3], Metzner D. [1,2], Toohey M. [1,2], Gleixner S.[2], Scheef H. [2], Zander S[2]

[1]SFB 574
[2]GEOMAR, Kiel, Germany
[3]MPI-M, Hamburg, Germany

This study gives an overview of the climate effects of explosive volcanic eruptions at the Central American Volcanic Arc (CAVA) for the last 200 ka, obtained during the third phase of the SFB574 project. Major volcanic eruptions in the tropics which directly inject high SO_2 amounts into the stratosphere have a significant impact on the global climate. Within weeks the sulfur gases build volcanic sulfate aerosols, which remain in the stratosphere between 3 to 6 years according to the large scale meridional overturning circulation in the stratosphere, called the Brewer-Dobson circulation (BDC). Due to the different strengths of the BDC in the Northern Hemisphere and Southern Hemisphere, and to its seasonality, we find different climate effects between the two hemispheres. To address the role of the seasonality, and eruption strength, we perform a set of model simulations with stratospheric SO_2 injections of different magnitudes varying between weak and extremely strong eruptions during different seasons. We particularly address the effects from the stratosphere down to the surface, showing the dominant atmospheric modes during winter: the Northern and Southern Annular Modes (NAM and SAM). We explore the mechanisms for the annular mode volcano response, highlighting atmospheric and oceanic circulation changes and possible implications for ice core proxies.

Bromine in Plininan eruptions: A paleo-ozone killer?

S. Kutterolf[1], T. H. Hansteen[1], K. Appel[2], A. Freundt[1], K. Krüger[1], W. Peréz[1], H. Wehrmann[1]

1) SFB 574, GEOMAR | Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
2) HASYLAB at DESY, a research centre of the Helmholtz Association, Hamburg, Germany

Large explosive volcanic eruptions inject gases, aerosols and fine ash into the stratosphere, potentially influencing climate. Emissions of chlorine (Cl) and bromine (Br) from large eruptions play an important role for catalytic destruction of ozone in the stratosphere, but hitherto the effects of volcanic Br release with respect to an extended pre-historic time series is not known on a regional or global scale.
The bromine release from 31 large explosive eruptions in Central America covering the last 200 ka and a whole subduction zone was determined with the petrologic method. Melt inclusions in volcanic minerals were analyzed using a new optimized synchrotron radiation X-ray fluorescence microprobe set-up. The eruptions produced Br outputs of 1 to 1100 kt per event, resulting in an average Br emission of 127 kt per eruption, which, together with Chlorine, would increase the Equivalent Effective Stratospheric Chlorine (EESC) up to 600% of the pre-industrial stratospheric concentration if only 10% of the emitted halogens reach the stratosphere. Based on our estimated Central American Br and Cl loading to the stratosphere, we conclude that, in contrast to the general opinion until now, many large tropical volcanic eruptions had and have the potential to substantially deplete ozone on a global scale, eventually forming (pre-industrial) ozone holes.

Time scales and potential controls of focused fluid flow at circum-Pacific margins: deciphering microbially mediated carbonates from micron to global perspectives

Liebetrau V. [1], Augustin N. [1], Eisenhauer A. [1], Fietzke J. [2], Suess E. [1], Kutterolf S. [1], Thiel V. [3], Han X. [4], Abegg F. [2], Linke P.[1]

[1] SFB 574, GEOMAR, Wischhofstr. 1-3, 24148 Kiel, Germany
[2] GEOMAR | Helmholtz Centre for Ocean Research Kiel, Germany
[3] Geobiology Group, Geoscience Centre, University of Göttingen, Göttingen, Germany
[4] Guangzhou Marine Geological Survey, Guangzhou 510075, China

Focused gas and fluid flow of cold seep ecosystems is often characterized by carbonate precipitation processes fueled by hydrocarbon-rich fluids and microbial activity. In various geological settings the seabed leakage is methane dominated and accompanied by the formation of long-lasting hard substrates and open channels. These fluid pathways are connecting deeper levels of the sediment column with the bottom water, bridging the diffusive processes at the sediment/water-interface. Understanding and quantifying feedback mechanisms between hydrocarbon-sources, ocean chemistry, and climate requires detailed data about the dynamics of seafloor methane emanation throughout geological time.
Authigenic carbonates from these ecosystems represent in many cases unique archives of marine methane emanation by their geobiological, geochemical, mineralogical, and structural inventory. Precise and high resolution geochronology of these archives provides new insights into the rate and duration of precipitation processes, the related microbial activity and a base for the reconstruction of paleoactivity of natural seepage. The actual data set of our compilatory study is spanning a wide range in space and time. It covers different geological circum-Pacific settings (South China Sea,

Costa Rica & Nicaragua, Chile, New Zealand), including more than 200 thousand years old archives (Hydrate Ridge, off Oregon) and recent methane-related carbonates from Black Sea and Mediterranean Sea. Special emphasis is actually given to new insights into growth structures, emplacement processes, mineralogy and high resolution geochemistry of mud mound and escarpment related carbonates from the Central American Forearc as well as to new findings on seep systems off Chile (cruise Sonne 210) applying a ROV-operated diamond chain saw sampling system. In a rather complex case study carbonate drill cores decipher the late stage evolution of mound growth and related methane enriched fluid emanation during the last 70 000 years off Costa Rica. A broad range in $\delta^{13}C$ from -22 to -36‰ (mounds) and -43 to -56‰ (escarpment) is covered, reflecting different hydrocarbon sources and/or varying fluid/seawater-ratios. Whereas the $\delta^{18}O$ signatures indicate a systematic variation between 3.8 - 5.3‰ (mounds) and 4.2 - 5.1‰ (escarpment) in close correlation with their ages (U-Th geochronology [1]) and the record of seawater evolution.
Combining high resolution observations of growth structures (fluorescence microscopy) and analyses of Cl-S-C distribution pattern (electron microprobe) decipher multiple phases of carbonate precipitation separated by micrometer scaled layers of residual organic matter (e.g. 50 alternations on 3 mm). The latter are interpreted to be attached onto crystal surfaces during phases of rather stagnant or low fluid flow, respectively.
On long time scales, the circum-Pacific data set indicates sea level decrease as an important enhancement factor for focused fluid flow via increasing pore water buoyancy, destabilization of gas hydrates and related fluxes from underlying free gas deposits upon hydraulic pressure release. Data from tectonically highly active settings imply structural changes as major control on initiation and position of cold seeps and their activation on short time scales [2, 3].

References: [1] Hammerich et al. (2007) Terra Nostra. [2] Kutterolf et al. (2008) Geology, doi: 10.1130/G24806A [3] Liebetrau et al. (2010) MG, doi:10.1016/j.margeo.2010.01.003.

Density Structure and Geometry of the Costa Rican Subduction Zone from 3D Gravity Modeling and Local Earthquake Data

Oscar H. Lücke [1,2], Ivonne G. Arroyo [3]

[1] Institut für Geowissenschaften, Abt. Geophysik, Christian-Albrechts-Universität, Kiel, Germany
[2] Universidad de Costa Rica, Ciudad Universitaria Rodrigo Facio, 214-2060 San José Costa Rica.
[3] SFB 574, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany.

The eastern part of the oceanic Cocos Plate presents a heterogeneous crustal structure due to diverse origins and ages as well as plate-hot spot interaction. The complex structure of the oceanic plate directly influences the dynamics and geometry of the subduction zone along the Middle American Trench. In this work, an integrated interpretation of the slab geometry is presented based on three-dimensional density modeling of satellite-derived gravity data constrained by seismological information obtained by local networks. Results show the continuation of steep subduction from the Nicaraguan margin into northwestern Costa Rica followed by a shallower slab under the Central Cordillera toward the end of the Central American Volcanic Arc. To the southeast of the termination of the volcanic arc, the slab appears to steepen and continue as a coherent structure until reaching the landward projection of the Panamá Fracture Zone. Overall a gradual change in the depth of intra-plate seismicity is observed reaching 220 km for the northwestern part and becoming shallower toward the southeast where it reaches a maximum depth of 70-75 km. The changes in the depth of the observed seismicity correlate with changes in the density structure of the subducting slab and may indicate that differences in the state of initial hydration of the oceanic lithosphere affect the depth reached by dehydration reactions in the subduction zone.

Density Structure and Geometry of the Costa Rican Subduction Zone from 3D Gravity Modelling and Local Earthquake Data

Oscar H. Lücke [1,2], Ivonne G. Arroyo[3], Hans-Jürgen Götze[1]

[1] Institut für Geowissenschaften, Abt. Geophysik, Christian-Albrechts-Universität, Kiel, Germany
[2] Universidad de Costa Rica, Ciudad Universitaria Rodrigo Facio, 214-2060 San José Costa Rica.
[3] SFB 574, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany.

The eastern part of the oceanic Cocos Plate presents a heterogeneous crustal structure due to diverse origins and ages as well as plate-hot spot interaction. The complex structure of the oceanic plate directly influences the dynamics and geometry of the subduction zone along the Middle American Trench. In this work, an integrated interpretation of the slab geometry is presented based on three-dimensional density modelling of satellite-derived gravity data constrained by seismological information obtained by local networks. Results show the continuation of steep subduction from the Nicaraguan margin into northwestern Costa Rica followed by a shallower slab under the Central Cordillera toward the end of the Central American Volcanic Arc. To the southeast of the termination of the volcanic arc, the slab appears to steepen and continue as a coherent structure until reaching the landward projection of the Panama Fracture Zone. Overall a gradual change in the depth of intra-plate seismicity is observed reaching 220 km for the northwestern part and becoming shallower toward the southeast where it reaches a maximum depth of 70-75 km. The changes in the depth of the observed seismicity correlate with changes in the density structure of the subducting slab and may indicate that differences in the state of initial hydration of the oceanic lithosphere affect the depth reached by dehydration reactions in the subduction zone.

Density Structure of the Central American Lithosphere from Satellite Derived Gravity Data: highlighting the need for data acquisition at a level between the Earth's orbit and its surface

Oscar H. Lücke [1,2], Hans-Jürgen Götze[1], Guillermo E. Alvarado[3]

[1] Institut für Geowissenschaften, Christian-Albrechts-Universität, Kiel, Germany
[2] Universidad de Costa Rica, San José, Costa Rica.
[3] ICE, San José, Costa Rica.

Gravity data from the combined geopotential model EGM2008 was interpreted via forward modelling to outline the three dimensional lithospheric density structure along the Middle American Trench, as well as the segmentation of the oceanic Cocos and Nazca plates and the overriding Caribbean Plate. Results for the Moho depth obtained from the density model are presented. The Quaternary volcanic arc correlates with a maximum Moho depth of 44 km in western Guatemala. To the southeast of the continental shelf, the Caribbean plate shows Moho depths between 20 and 12 km whereas to the north, values as shallow as 8 km are observed at the Cayman trough. For the oceanic Cocos Plate, depths between 16 and 21 km are obtained for the Moho along the Cocos ridge contrasting with values between 15 and 12 km for the seamount segment and 8 and 11 km for the segments of the crust that are not affected by the Galapagos hot-spot track. These results were obtained from regional scale modelling of first order lithospheric discontinuities. Combined geopotential models such as EGM2008 based on gravity data from the GRACE mission, satellite altimetry offshore and surface gravity measurements onshore, and the latest EIGEN-6C which additionally includes data from the LAGEOS and GOCE satellite missions, have proved to be a viable source of data for the regional scale modelling of the solid Earth. The current combined models possess sufficient spatial resolution for the interpretation of first order lithospheric discontinuities such as the Moho, the lithosphere-asthenosphere boundary and the subducted slab. However, for the shorter wavelengths, the combined models still rely on the coverage of surface gravity stations. In Costa Rica, the available gravity databases lack coverage in certain key areas. This lack of coverage is associated with regions in which ground access is not possible due mainly to: rugged topography, vegetation coverage, and lack of infrastructure. In order to achieve a satisfactory coverage of these areas and the spatial resolution necessary for local scale models, an intermediate level between the orbit and the surface is needed. For this reason, an airborne gravity survey is planned and should provide comprehensive data coverage of the Costa Rican landmass and the necessary spatial resolution for the modelling of local structures.

Southern Hemisphere Climate Response to an extremely large tropical Volcanic Eruption: Simulations with the MPI-ESM

D. Metzner [1,2], K. Krüger [1,2], D. Zanchettin[3], M. Toohey [1,2], C. Timmreck [1,3]

1 SFB 574
2 GEOMAR | Helmholtz Centre for Ocean Research Kiel, Kiel, Germany.
3 MPI for Meteorology, Hamburg, Germany.

Using an Earth System Model, we investigate the potential Southern Hemisphere (SH) climate response to an extremely large volcanic eruption. The volcanic radiative forcing is calculated offline with a global aerosol model taken into account the formation and development of the volcanic aerosol size distribution from an initial stratospheric injection of 700 Mt SO_2 corresponding to that estimated for the VEI>7 volcanic eruption of Los Chocoyos in Guatemala 84 ka BP. Due to the extremely large volcanic radiative forcing, the surface cools over almost the entire SH. A significant positive phase of the Southern Annual Mode (SAM), persisting for at least 12 months, characterizes the simulated post-eruption SH atmospheric circulation. Significant changes of surface temperature, precipitation and wind fields result from a distinct increase in magnitude and poleward movement in position of the SH westerlies. This is associated with temporary modifications in the upper ocean circulation in the Antarctic Circumpolar Current region. Due to the propagation of the forced anomalies into the deep ocean layers, the anomalous oceanic state persists well beyond the atmospheric response timescale. Significant negative temperature anomalies in the SH ocean propagate down to ~2000 m during the first ~20-50 post-eruption years, and persist for the entire simulated 200 years. A multicentennial anomaly in the SH ocean heat content represents the longest lived volcanically-forced signal detectable in the simulated climate.

Radiative Forcing and Climate Impact of explosive Central American Volcanic Arc Eruptions for the last 200 ka

Doreen Metzner [1,2], Steffen Kutterolf [1,2], Matthew Toohey [1,2], Claudia Timmreck [1,3], Ulrike Niemeier[3], Armin Freundt [1,2], Kirstin Krüger [1,2]

1 SFB 574
2 GEOMAR | Helmholtz Centre for Ocean Research Kiel, Kiel, Germany.
3 MPI for Meteorology, Hamburg, Germany.

We petrologically estimated SO_2 emissions from 36 detected Plinian volcanic eruptions occurring at the Central American Volcanic Arc (CAVA) during the past 200,000 years. Using this record and simple parameterized relationships collected from past studies we derive estimates of maximum volcanic aerosol optical depth (AOD) and radiative forcing (RF) for each eruption. For selected CAVA eruptions comprising different SO_2 emission strengths, AOD and RF time series are derived in parallel from simulations with the global aerosol model MAECHAM5-HAM. The model shows a relationship between stratospheric SO_2 injection and maximum global mean AOD that is linear for smaller volcanic eruptions (<4 Mt SO_2), and non-linear for larger ones (≥4 Mt SO_2), which is qualitatively and quantitatively consistent with the relationship used in the simple parameterized method. Potential climate impacts of the selected CAVA eruptions are estimated using an earth system model of intermediate complexity by RF time series derived (1) directly from the global aerosol model, and (2) from the simple parameterized method assuming a 12-month exponential decay of global AOD. We find that while the maximum AOD and RF values are consistent between the two methods, their temporal evolutions are significantly different. As a result, simulated maximum temperature anomalies and the duration of the temperature response depend on which RF time series is used, varying between 2.1 K and 3.1 K and ~ 60 and 90 years for the largest eruption of the CAVA data set. The presented results can be used to estimate the volcanic forcing and potential climate impacts from sulfur emissions, sulfate aerosol or AOD data for any tropical eruption that reached the stratosphere in the past but also in the future.

Automatic classification of volcano-seismic signals using ensemble methods

Mora-Stock, C [1] and Bravo, C [2]
[1] Institut für Geowissenschaften, Christian-Albrechts-Universität - Kiel, Germany
[2] Department of Industrial Engineering, Universidad de Chile - Santiago, Chile

Volcanoes present different types of seismic activity depending on the source origin, such as tremors, long-period, and volcano-tectonic events. In Chile, Villarrica and Llaima are two of the most active volcanoes, constantly presenting seismicity that can be classified into these different types. To obtain a faster and reliable classification of future activity, pattern recognition ensemble methods were constructed using neural networks and support vector machines. The method for classification here presented, will be use to analyze data from two temporary networks in Llaima and Villarrica installed during Nov. 2009 and Apr. 2011.

Comparison of volcano-seismic activity in Llaima and Villarrica before and after the Maule M8.8 earthquake in Southern Chile

Mora-Stock, C.(1), Thorwart, M.(1), Wunderlich, T.(1), Bredemeyer, S.(2), Hansteen, T.(2), Rabbel, W.(1)

(1) SFB 574, Institut für Geowissenschaften, Christian-Albrechts-Universität - Kiel, Germany
(2) SFB 574, GEOMAR, Kiel, Germany

Llaima and Villarrica are two of the most actives volcanoes in the Southern Volcanic Zone in the Chilean Andes, with different type of activity and edifice. Llaima is a close vent volcano with constant seismic activity, while Villarrica is an open vent volcano with lava lake at the summit and constant degassing. The relation between volcano eruptions following a great earthquake has been studied in different cases around the world, and it has been the case for the 1960 Valdivia earthquake in southern Chile, where Llaima and Villarrica presented eruptions on the following months to years. This study characterize the volcano-seismic activity in the months before and after the M8.8 Maule earthquake. Time series for tremors, long period and volcano tectonic events were obtained from the catalogue of the Volcanic Observatory of the Southern Andes (OVDAS in Spanish) and from the continuous record of the SFB 574 temporary volcanic networks. In Villarrica volcano, peaks of activity of tremor and long period events were observed months prior to and after the earthquake, followed by degassing activity, which is consistent with an increase in the activity related to fluids (gas and magma). While in Llaima volcano, a high increase in the volcano tectonic activity was observed directly after the earthquake, a possible structural adjustment response. Pressure change and normal stress were calculated for the Maule earthquake (M8.8) giving results two orders of magnitude lower in comparison to the ones obtained for Valdivia earthquake (M9.5). Giving the sustained activity and the nature of response, it is possible to state that the Maule earthquake affected these volcanoes in some way, but given the location and the insufficient critical state of both edifices, it was not possible to generate a great eruption.

Volcano seismicity at Villarrica volcano

Mora-Stock C., Thorwart M., Wunderlich, T., Rabbel, W.

SFB 574, Institut für Geowissenschaften, Christian-Albrechts-Universität - Kiel, Germany

A dense temporary volcanic network was installed between 28th February and 15th March, 2012, around and on top of Villarrica volcano in Southern Chile. The network comprised 60 one-component DSS-Cubes stations and 15 three-component DSS-Cubes, with 45 of these stations installed directly on the volcanic edifice. Data collected by the stations is presented, as well as some characteristics of the activity at Villarrica volcano. Future work considers the classification, location and source origin of the activity, and a volcano tomography using different techniques for Villarrica.

Multiparameter surveillance of the Llaima and Villarrica volcanoes (Southern Chile): The near real-time approach

C. Mora-Stock (1), M. Thorwart (1), T. Wunderlich (1), S. Bredemeyer (2), W. Rabbel (1), and T. H. Hansteen (2)
(1) SFB 574, Christian-Albrechts-Universität zu Kiel, Institut für Geowissenschaften, Kiel, Germany
(2) SFB 574, GEOMAR, Kiel, Germany

Llaima and Villarrica are two of the most actives volcanoes in the Southern Volcanic Zone in the Chilean Andes, with different type of activity and edifice. Llaima is a closed vent volcano with constant seismic activity, while Villarrica is an open vent volcano with a constantly degassing lava lake at the summit. Since 2009, seismic networks have been deployed at Llaima and Villarrica, and mini-DOAS stations continuously recording SO_2 degassing were installed in 2010 and 2009, respectively. The response of Llaima and Villarrica volcanoes to local volcano-seismic activity, to regional events, and also to the tectonic activity related to the great Maule earthquake (M8.8) in February 2010 are investigated. Time series for tremors, long period and volcano tectonic events were obtained from the catalogue of the Volcanic Observatory of the Southern Andes (OVDAS in Spanish) and from the continuous record of the SFB 574 temporary volcanic network. At Villarrica volcano, peaks of activity of tremor and long period events were observed months prior to and after the earthquake, which is consistent with an increase in the activity related to fluids (gas and magma). Degassing at Villarrica followed a complex pattern, where increased degassing rates preceded the M8.8 Maule earthquake by three months. Days before the earthquake, there was a strong decrease in degassing, and finally by a persistent degassing maximum about one month after the earthquake. At Llaima, a high increase in the volcano tectonic activity was observed directly after the earthquake, consistent with a possible structural adjustment response. Also, continuous low fumarolic degassing was observed during and after the earthquake at Llaima, but this activity could be related to the closing of the eruption cycle started in January 2008. We aim at a better understanding of the volcanic systems through the combination of both degassing and seismic data, and also detection of satellite-based thermal anomalies. Ongoing work focuses on the quantification of magma volumes involved, location of chambers and finally on tomographic structures of Villarrica.

NSF GeoPRISMS Program: Amphibious Continental Margin Studies Around the World

Julia Morgan

GeoPRISMS Program, Dept Earth Science, Rice University, Houston, TX

The GeoPRISMS Program, successor to MARGINS, is an interdisciplinary, NSF-funded community of researchers studying the origin and evolution of continental margins, with a focus on rifting and subducting margins. The GeoPRISMS mission is to
"…investigate the coupled geodynamics, earth surface processes, and climate interactions that build and modify continental margins over a wide range of timescales (from s to My), and cross the shoreline, with applications to margin evolution and dynamics, construction of stratigraphic architecture, accumulation of economic resources, and associated geologic hazards and environmental management."
The precursor MARGINS Program consisted of four initiatives, enabling research at six focus areas around the world. The structure and organization of the GeoPRISMS Program was defined during three community planning workshops in 2010-2011, building upon the successes of MARGINS. The result was two Initiatives, five primary sites for focused study, and ten thematic studies to complement and complete the primary site objectives, including global comparisons. The Initiatives and associated Primary Sites are: (a) Subduction Cycles and Deformation (SCD), encompassing the former MARGINS SEIZE and SubFac initiatives, with focused studies along the Alaska-Aleutians Subduction Zone, Cascadia Subduction Zone, and New Zealand, and (2) Rift Initiation and Evolution, encompassing and expanding upon MARGINS RCL, with focused studies along the Eastern North American Margin (ENAM) and East African Rift System (EARS). Both initiatives retain an integrated research approach, combining field, theory, modeling, and experimental components.
Three GeoPRISMS planning workshops have taken place within the last year to determine the scientific targets and research priorities for the North American primary sites. Two additional planning workshops are anticipated in the next year (2013-14) for New Zealand and East Africa. Strong

international collaborations played a key role in the extraordinary accomplishments of the MARGINS Program, with particularly strong ties with SFB574 guiding research efforts along the Central American subduction zone. Similar opportunities for coordinated research exist through the GeoPRISMS Program, both at North American and international primary sites. I will review the community-developed implementation plans for the GeoPRISMS primary sites, with an emphasis on opportunities for such international collaborations, and entertain open discussions about specific projects and collaborations designed to achieve the scientific objectives of the program.

Earthquakes, peninsulas, fluids, and climate - or: what controls plate margins at the human time scale?

Onno Oncken with IPOC Research Group

GFZ Potsdam, Telegrafenberg, D-14473 Potsdam, Germany, oncken@gfz-potsdam.de

Accumulation of deformation at convergent plate margins is recently identified to be highly discontinuous and transient in nature: silent slip events, non-volcanic tremors, afterslip, fault coupling and complex response patterns of the upper plate during a single as across several seismic cycles. Segments of convergent plate margins with high recurrence rates and at different stages of the rupture cycle like the Chilean margin offer an exceptional opportunity to study these features and their interaction resolving behaviour during the seismic cycle and over repeated cycles. An active international initiative (IPOC; Integrated Plate Boundary Observatory Chile) addresses these goals with research groups from IPG Paris, Seismological Survey of Chile, Free University Berlin, Potsdam University, Hamburg University, GEOMAR Kiel, GFZ Potsdam, and Caltech (USA) employing an integrated plate boundary observatory and associated projects.
We focus on the south Central Chilean convergent margin and the North Chilean margin as natural laboratories. Here, major recent seismic events have occurred (south Central Chile: 1960, Mw = 9.5; 2010, Mw=8.8; North Chile: 1995, Mw = 8; 2001, Mw = 8,7; 2007; Mw: 7,8) or are expected in the very near future (Iquique, last ruptured 1877, Mw = 8,8) allowing observation at critical time windows of the seismic cycle. Seismic imaging and seismological data have allowed us to relocate major rupture hypocentres and to locate the geometry of the locked zone in both areas. The reflection seismic data exhibit well defined changes of reflectivity and Vp/Vs ratio along the plate interface that can be correlated with different parts of the coupling zone as well as with changes during the seismic cycle. Observations suggest an important role of the hydraulic system, an inference that is strongly supported from recent findings along the exhumed, fossil seismogenic coupling zone of the European Alps.
Neogene surface deformation in Chile has been complex exhibiting tectonically uplifting areas along the coast driven by interseismically active reverse faulting. In addition, we observe coseismically subsiding domains along other parts of the coast. Moreover, the coseismic and interseismic vertical displacement identified is not coincident with long-term vertical motion that probably is superseded by slow basal underplating or tectonic erosion occurring at the downdip parts of the seismogenic zone causing discontinuous uplift. Hence, kinematics varies during a single seismic cycle, and: the dominant deformation observed within one seismic cycle contrasts with long term deformation as evidenced by topography and major structures. Finally we note that the characteristic peninsulas along the South American margin constitute stable rupture boundaries and appear to have done so for a protracted time as evidenced by their long-term uplift history since at least the Late Pliocene that points to anomalous properties of the plate interface affecting the mode of strain accumulation and plate interface rupture.

The 2011 Nabro eruption, Eritrea: a preliminary report

Clive Oppenheimer

University of Cambridge, UK

The 2011 eruption of Nabro volcano in Eritrea is of great scientific interest and has had substantial impacts in the remote part of Afar in which it is located. It is sited in the extensional zone of Afar, close to the Mesozoic crustal block of the Danakil Alps. It is a predominantly trachytic edifice, with an 8 km wide caldera and extensive ignimbrites exposed on the flanks of the volcano. The 2011 eruption began shortly before 20:42 UTC on 12 June following intense seismicity. It is the first eruption of Nabro on record, highlighting the potential of caldera systems to erupt without warning. It is also associated with the first seismicity of note recorded in this part of the rift. Comparatively little is known about magma differentiation, storage and transport mechanisms and eruptive processes in such tectonic settings. I will summarise a range of observations of the eruption made with remote sensing techniques and report on the initial findings of fieldwork on the volcano carried out last October.

Birth and Death of Subduction Zones: The Geochemical Evidence

Julian Pearce

School of Earth and Ocean Sciences, Cardiff University, UK

Volcanic arc geochemistry provides important insights into the nature and evolution of subduction systems. Typically, each arc follows an evolutionary ‘life cyle’ which begins with their birth and follows into youth and maturity, interspersed with mid-life crises such as ridge subduction and seamount collisions. It ends with the death of the arc by collision with a subducting margin, and also its ‘resurrection’ whereby subduction-modified mantle is recycled during the post-collision period to produce a final episode of arc-like volcanism.
The aim of this presentation is to summarise the geochemical evidence for some of the processes associated with the initial and final parts of this cycle. Of the types of birth, the most interesting is the intraoceanic type where there is now good evidence for a sequence of slab sinking and rollback before true arc volcanism begins. In its type area of the Izu-Bonin-Mariana forearc, and in many on-land analogues, the earliest arc volcanism is boninitic in character. The composition of the boninites (high MgO, high silica, low Ti) indicates shallow, hydrous melting of depleted mantle, a predictable consequence of near-trench arc magmatism. A particularly noticeable feature is the large positive Hf and Zr anomalies on extended REE plots, which are noticeably distinct from the negative anomalies that characterise active arc volcanism in the same region. Modelling of these anomalies using, in particular, Hf-Nd isotope systematics, gives the most probable origin of the boninite signature as a subduction component derived from shallow fusion of subducted oceanic crust, in which residual amphibole retains Nd while high temperatures allow zircon dissolution leading to high Hf. The first crust to subduct encounters hot mantle that has had no time to be cooled by earlier subduction of oceanic lithosphere, and so can extract heat from the mantle wedge to reach fusion temperatures. With time, the cooling of the system leads to a predominance of dehydration and low-temperature melting only of sediments, giving negative Hf anomalies.
Following this relatively hot birth and cooler life (with the exception of mid-life crises such as ridge subduction and slab-edge mantle flow) of subduction systems, there is evidence also for a relatively hot death. Again Hf-Nd systematics also provide key evidence. Although sediment and crustal subduction do not produce the positive Hf anomalies associated with subduction initiation, the vectors for mixing of mantle wedge with subduction components do indicate that these components contain high Hf contents, again an indication of high temperatures. The likely explanation is that the cessation of subduction brings an end to the cooling of the mantle wedge, allowing the subducted crust and sediments to reach temperatures well above their solidi. Interestingly, the final fate of the subducted slab is now believed, supported by geochemical evidence for shallow melting of depleted but subduction-enriched mantle, to be a post-collision episode of intense arc-like magmatic activity resulting from roll-back and detachment of final section of the subducted plate. Thus there are some interesting similarities between the birth and death of subduction zones, notably in the high slab temperatures and importance of slab roll back during both periods of arc evolution.

Bend-Faulting, Serpentinization, and Mantle Recarbonization at Oceanic Trenches

Jason Phipps Morgan

Cornell University, Ithaca, NY, USA

It is well known that mid-ocean ridges are a key site for chemical interactions between oceanic crust and the hydrosphere, and that these interactions modulate the chemistry of the oceans. As SFB574 has confirmed, subduction forearcs are also key sites of chemical fluid-rock exchanges. These fields are relatively mature. However, it is becoming increasingly evident that the oceanic lithosphere may also strongly interact with the hydrosphere during plate subduction, as it bends — by bend-faulting — when it enters a trench. I briefly review recent seismic evidence collected by the SFB574 and others that suggests that bend-faulting is associated with ~10-20% serpentinization in a layer extending at least 5km below the Moho. If this serpentine forms with a 1% carbonate fraction (note that at least this degree of carbonitization occurs during mid-ocean-ridge serpentinization processes), then bend-faulting-linked serpentinization will consume an atmosphere's worth of CO_2 every 40,000 years, and it is likely that the carbonate storage in serpentinized subducting lithosphere exceeds that in overlying oceanic crust and sediments. This poorly-understood geological process clearly merits further study, with significant potential implications for the global carbon cycle, for the geochemical evolution of the mantle, and for human exploitation for potential carbon sequestration at oceanic trenches. CO_2-rich fluids released by deserpentinization reactions may even play a role in 'lubricating' the subduction channel, and in the volatilization of the forearc. While bend-faulted Moho lies within the potential drilling window for the Chikyu marine drilling platform, it may prove to be much easier to gain constraints on bend-fault-related serpentinization from observations on Alpine serpentinites. Another critical observation to begin to document this interaction would be to find and study an active site of bend-fault fluid venting at the seafloor.

Contrasting compositional trends of rocks and olivine-hosted melt inclusions from Cerro Negro volcano (Central America): Implications for decompression-driven fractionation of hydrous magmas

Maxim V. Portnyagin, Kaj Hoernle & Nikita L. Mironov

SFB 574, GEOMAR, Kiel, Germany

Melt inclusions in olivine Fo83-72 from tephras of 1867, 1971 and 1992 eruptions of Cerro Negro volcano represent a series of basaltic to andesitic melts of narrow range of MgO (5.6-8 wt%) formed by ~46 wt% fractional crystallization of olivine (~6 wt%), plagioclase (~27 wt%), pyroxene (~13 wt%) and magnetite (<1 wt%) from primitive basaltic melt (average SiO_2=49 wt%, MgO=7.6 wt%, H_2O=6 wt%) as it ascended to the surface from the depth of about 14 km. The crystallization occurred at increasing liquidus temperature from 1050 to 1090 oC in the pressure range from 400 to 50 MPa and was induced by release of mixed H_2O-CO_2 fluid from the melt at decreasing pressure. Matrix glass compositions fall at the high-Si end of the melt inclusion trend and represent the final stage of melt crystallization during and after eruption. The bulk compositions of erupted Cerro Negro magmas (tephras and lavas) range from high- to low MgO (3-10 wt%) basalts, which form a compositional array crossing the trend of melt inclusions so that virtually no rock from Cerro Negro has composition akin to true melt represented by the inclusions. The variations of the bulk magma (rocks) and melt (melt inclusions) compositions can be generated in a dyke connecting deep primitive magma reservoir with the Cerro Negro edifice. While the melt inclusions represent the compositional trend of instantaneous melts along the magma pathway at decreasing pressure and H_2O content, occurrence of low-Mg to high-Mg basalts reflect the process of phenocryst re-distribution in progressively evolving melt. The crystallization scenario is anticipated to operate everywhere in dykes feeding basaltic volcanoes and can explain the predominance of plagioclase-rich high-Al basalts in island arc as well as typical compositional variations of magmas during single eruptions.

From the Valdivia Fracture Zone to the Villarrica volcanic complex - seismic evidence of a link between subducted oceanic faults and volcanism

W Rabbel (1), Y Dzierma (1), M Thorwart (1), T Wunderlich (1), I Koulakov (2), K Hoernle (3), and H. Wehrmann (3)

(1) SFB 574, University of Kiel, Institute of Geosciences, Geophysics, Kiel, Germany ,
(2) Institute for Petroleum Geology and Geophysics, Novosibirsk, Russia
(3) SFB 574, GEOMAR, Kiel, Germany

The south-central Chilean subduction zone was investigated at 39-40°S by a passive seismic experiment. The investigation area comprises the maximum slip of the great 1960 Mw 9.5 Valdivia earthquake. The incoming Nazca plate is permeated by a number of major fault zones including the Valdivia fault zone and the Mocha fault zone which seem to have behaved as a barriers for the rupture propagation of large earthquakes in the past. The investigated sector is also home to the Villarrica volcano - one of South America's most active volcanoes. In the extension of the Valdiva fault zone we observed a cluster of increased seismicity in the subducting plate at depths between 80 km and 120 km, where dehydration of the subducting plate occurs. The focal plane solutions of this cluster show predominantly strike-slip motion. Tomographic images show decreased P- and S-velocity and increased ratio between the seismic cluster and the volcanic center of Villarrica, Quetrupillán and Lanin, corresponding to an increased content of fluids or melt. Additional geochemical investigations show that the magma of Villarrica volcano has an enhanced fluid signal compared to the other volcanoes of the Southern Volcanic Zone of Chile. It can be assumed that the Valdivia fault zone serves as the source for the fluids. Before the plate subducts, water can penetrate the plate through faults within the Valdivia fault zone. Serpentinization would build the water into minerals. Inside the subduction zone the Valdiva fault zone is reactivated by dehydration reactions at a depth of about 100 km. The released fluids rise towards the volcanic center causing the tomographic anomalies. At the end this leads to an increased degree of melting and a higher activity of Villarrica volcano.

An overview of ongoing studies on the lateral changes of the plate-boundary structure of Middle America, the 3D multichannel seismic experiment at the CRISP area, and the north Chile region

C. R. Ranero(1), V. Sallares(1), R. von Huene(2), N. Bangs(3), E. Silver(4), A. Calahorrano(1), U. Barckhausen(5), C. Reichert(5)

1 Barcelona Center for Subsurface Imaging, CSIC, Barcelona, Spain
2 Davis University, CA, USA
3 Institute of Geophysics, University of Texas, USA
4 University of Santa Cruz, CA, USA
5 BGR. Hannover.

We will present an overview of recent activities offshore Pacific Central America that originated from related to the SFB. Current work includes the integration of existing seismic data and earthquake rupture models of Costa Rica and Nicaragua analyzed trying to understand the relationship between mega-thrust fault properties and seismogenesis. We will also present a preliminary interpretation of 2D seismic data around Osa Peninsula in the light of the recent CRISP iODP leg 334 drilling results and multibeam bathymetry. The CRISP area was surveyed in 2011 with a new 3D multichannel seismic data collected to prepare iODP expedition 344 and the deep riser drilling. The data were collected with USA R/V Marcus G. Langseth using 4 streamers, 6 km long and 2 well tuned 3400 c.i. airgun arrays. The data have been commercially processed by Repsol-CGG (Madrid) and ongoing work will focus of 3d pre-stack depth migration (Repsol, Houston). Preliminary post-stak time migrations of the 3D data show promising images of the deformation of the overriding plate and plate boundary reflections. Work continues in northern Chile with the Cinca project seismic data and a compilation of multibeam bathymetry. A set of seismic profiles collected perpendicular to the margin shows that the ocean plate bending-related deformation, involving the mantle, initiates well before the lithosphere plunges into the trench. Also the combination of seismic images and swath bathymetry shows a remarkable lateral variability in the intensity and style of deformation at the trench. The

deformation appears to be controlled by the combined effect of changes in trench strike and pre-existing ocean plate structure, and changes abruptly along the subduction zone.

Numerical modeling of volatile cycling beneath subduction zones

Lars Rüpke [1,2], Karthik Iyer [1,2], Jörg Hasenclever [1,3], Jason Phipps Morgan [1,4]

[1] SFB 574, Fluids and Volatiles in Subduction Zones
[2] GEOMAR, Helmholtz Centre for Ocean Research Kiel
[3] Hamburg University
[4] Cornell University

The subduction zone water cycle, i.e. the hydration and dehydration of subducting oceanic lithosphere, is a key process in understanding arc magmatism and volatile recycling processes. However, budgets of the subduction zone water cycle continue to have large error bars attached to them. In this study we will show how numerical modeling techniques can help to integrate various geological, geophysical, and geochemical datasets and to put bounds on the likely amounts of water being subducted, released into the arc melting region, and recycled into the deeper mantle.
To achieve this task we use a suite of numerical models of different complexity. Bending related faulting and hydration of the incoming lithosphere offshore Chile and Nicaragua is resolved using a novel reaction-transport model that couples water circulation to serpentinization reactions. We find that the temperature dependent kinetics of the serpentinization reaction are likely to control the hydration patterns at the trench outer rise leading to the formation of a band of highly serpentinized mantle around the 270°C isotherm. The models further predict a reduction in surface heat flow values in the outer rise region that is qualitatively consistent with observations. A detailed analysis reveals, however, that the observed seafloor temperature gradient in the bend-fault region is too low to be caused by 'one-pass' downward water flow into the serpentinizing lithosphere, but rather implies that bend-faults are areas of active hydrothermal flow, with the implied prediction that serpentine-sourced vents and chemosynthetic vent communities should be found in this deep-sea environment, too. Dehydration occurs deeper within the subduction zone by fluid releasing metamorphic reactions. These rising fluids flux the mantle wedge where they are commonly believed to trigger arc melting. Using 2D and 3D numerical models we have resolved the likely flow field in the mantle wedge. The kinetics of serpentinization results in maximum serpentinization around the 270°C isotherm of the incoming slab and also has the maximum potential for water release during dehydration at depth. The depth of maximum serpentinization increases with increasing plate age and is consistent with the spacing of double Benioff zones (DBZs) now observed in several subducting slabs. Finally, we have resolved the mantle flow field within the mantle wedge as a function of subduction rate and slab fluid release in 3D. We find that the classical 2D corner-flow solution is only a small subset of all possible mantle wedge flow fields. In fact, a more "natural" flow field involves 3D diapirs fuelled by low-density slab fluids rising from the slab surface. These diapirs provide a potential mechanism for decompression melting in the mantle wedge, break the classic corner flow solution, and illustrate the need for high-resolution three-dimensional subduction zones models.

Dewatering, Devolatilization, and Fluid Expulsion Patterns at Subduction Forearcs: Source Regions, Systematic Behaviors and the Role of Splay Faults

D.M. Saffer, R.M. Lauer

Dept. of Geosciences and Center for Geomechanics, Geofluids, and Geohazards, The Pennsylvania State University, United States

At many subduction zones, the geochemistry of pore waters sampled at seafloor seeps or in shallow boreholes indicates a contribution from deep, high-temperature sources. Identifying the source regions and flow pathways for these fluids is one key step toward quantifying volatile fluxes through subduction forearcs, and in understanding potential connections between fluid flow and the loci of excess pore pressures that affect plate boundary faulting mechanics. Here, we focus on numerous observations of pore water freshening (typically reported in terms of decreased [Cl]), high [B], and low δ11B. Pore water freshening is thought to result primarily from clay dehydration, whereas elevated B

signals are interpreted to reflect desorption of isotopically light B from pelitic sediments with increased temperature.
We use a simple model that tracks heating and compaction during progressive burial of subducted sediment. In combination with kinetic models of clay dehydration, and laboratory experimental data that constrain the distribution coefficient (Kd) for B in marine sediments as a function of temperature, we quantify the expected [Cl], [B], and δ11B within the subducting sediment section as a function of distance down-dip. A generic sensitivity analysis demonstrates that the relative timing of heating and compaction are important controls on the resulting pore water composition. For cold subduction, pore water freshening is maximized, because clay dehydration releases bound water into a low porosity sediment; B concentrations and isotopic signatures are relatively modest, because B is not completely desorbed. For hot subduction, the [B] and [Cl] signals are reduced, because heating and desorption occur at shallower depths and into larger porosities. Application of this model to the Costa Rica, N. Japan, and N. Barbados margins illustrates that clay dehydration and B desorption are viable mechanisms for the generation of observed geochemical signatures, and provides quantitative constraints on the source regions for deeply derived fluids. Interestingly, the locus of peak clay dehydration may coincide with zones of high seismic reflectivity, suggesting that it may be possible to image the source regions of these geochemically distinct fluids if they are associated with elevated pore fluid pressure.
Using coupled models of fluid flow and solute transport, we also investigate the role of splay faults that transect the forearc upper plate in the partitioning of fluid escape, fluid flow rates, and chemical transport. We show that for reasonable fault zone permeabilities, splay faults can capture a significant fraction (up to ~35%) of the total fluid inventory. Simulated flow rates of ~0.2 - 25 cm yr^{-1} are in excellent agreement with rates at seep sites on the continental slope inferred from geochemical profiles and heat flow data, and flow rates along the décollement near the trench estimated from drilling data. Simulated flow rates along the splay faults are sufficiently high to advect solutes from the plate boundary at depth to the seafloor, and are up to ~600 times higher than in adjacent areas. Geochemical signals associated with deeply sourced reactions should therefore be effectively channelized, with strong and highly localized expression where splay faults intersect the seafloor, or near structures with an underlying hydraulic connection to the plate boundary (e.g. mud mounds, mud volcanoes).

Holocene post-caldera magma evolution of Llaima volcano, Chile

Schindlbeck JC, Freundt A, Kutterolf S, Strehlow K

SFB 574, GEOMAR, Kiel, Germany

Llaima is a large active stratovolcano in the Southern Volcanic Zone in Chile. Field work in 2011 revised the postglacial stratigraphy after Naranjo&Moreno (1991) and led to the subdivision into units I to V. Postglacial activity started 13.500 years ago with caldera-forming eruption of two mafic ignimbrites (unit I). These are overlain by a sequence of three basaltic-andesitic to two dacitic lapilli fallout deposits and reworked tuffaceous sediments (unit II). At ~8600 cal BC a large Plinian eruption emplaced a compositionally zoned dacitic to andesitic fallout tephra (unit III) that became capped by subsequent andesitic surge deposits (unit IV) when the eruption became unstable. The following unit V represents a time interval of ~7000 years during which at least 30 basaltic to andesitic ash and lapilli fallout deposits with intercalated tuffaceous sediments and paleosols were emplaced.
Bulk-rock, mineral and glass chemical analyses constrain the vertical compositional changes of Llaima tephras. Tephra compositions switch between a calc-alkaline differentiation trend (unit I) and a more tholeiitic trend (units II-IV), with samples of unit V varying between both trends, indicating a strong control of $f(O_2)$ (and $P(H_2O)$) on the relative timing of Fe-Ti oxide fractionation. Moreover, iron rich fayalites that are in equilibrium with the glass composition occur in units II and III with calculated T-$f(O_2)$ close to the FMQ suggesting that late-stage fayalite precipitation involved crossing of the FMQ boundary. The younger unit V tephras and historical compositions define a second differentiation trend relatively enriched in K_2O, Rb, Ba and Zr; this is not the results of changing source conditions but can be explained by a stronger early olivine fractionation in the respective magmas.
Thermobarometric calculations based on amph, cpx-liq, plag-liq, ol-liq and Fe-Ti-oxide compositions constrain changing magma chamber positions over time. Storage depths were 14 - 19 km for unit I andesite and and varied between 10 to 17 km for unit II andesites and dacites. The compositionally zoned eruption of units III and IV withdrew dacite magma from ~10 km depth but andesite from a

deeper level of 13-15 km. Storage depths of unit V andesitic magmas ranged from 6 to 15 km. Based on temporally changing storage depths and differentiation paths, a 4-stage evolution of the postglacial magmatic system of the Llaima volcanic complex is proposed.
Reference: Naranjo JA, Moreno H (1991) Actividad explosiva postglacial en el volcan Llaima, Andes del Sur (38°45'S). Revista Geologica de Chile 18: 69-80

Some roots of the SFB 354 theme: Impact of natural disasters on society: Acahualinca and Nejapa

Hans-Ulrich Schmincke and SFB team

Nicaragua is a textbook region under constant siege by a wide range of natural hazards. Some historic disasters, such as the aftermath of the 1972 earthquake that destroyed Managua, trigger major revolutions. Moreover, the capital city has been built on the products of numerous Holocene volcanic eruptions. Ceramics found during SFB work below and above the deposits of Nejapa maar located in western Managua, date the eruption as between ca. 1.2 and 0.6 ka BP. A recurrence of the semiphreatomagmatic Nejapa eruption at this site or at one of the numerous neighboring vents along the Nejapa-Miraflores alignment would present a major volcanic hazard to Managua. We interpret the world famous footprints at Acahualinca located within the city as reflecting escape by a group of some 15 people from an ongoing eruption at Masaya crater at ca. 2.1 ka BP seeking refuge at the shore of nearby lake Managua.
Rausch J, Schmincke HU (2010) Nejapa Tephra: The youngest (c. 1 ka BP) highly explosive hydroclastic basaltic eruption in western Managua (Nicaragua). J Volcanol Geotherm Res 192: 159-177
Schmincke HU, Kutterolf S, Perez W, Rausch J, Freundt A, Strauch W (2009) Walking through volcanic mud: the 2,100-year-old Acahualinca footprints (Nicaragua) I: Stratigraphy, lithology, volcanology and age of the Acahualinca section. Bull Volcanol 71: 479-493 DOI 10.1007/s00445-008-0235-9
Schmincke HU, Rausch J, Kutterolf S, Freundt A (2009) Walking through volcanic mud: the 2,100 year-old Acahualinca footprints (Nicaragua) II. The Acahualinca people, environmental conditions and motivation. Int J Earth Sci, DOI 10.1007/s00531-009-0438-0

Submarine weathering and subduction dewatering across the Central Chilean forearc (~36°S)

Florian Scholz

SFB 574, GEOMAR, Kiel, Germany

The accretionary convergent margin off central Chile is an active tectonic setting, yet little is known about its hydrogeology and the distribution of deep-seated diagenetic processes. To overcome this gap, we present here a joint evaluation of data from ODP Legs 141 and 202 as well as new pore water and solid phase data from a gravity core transect at ~36°S.
Sediments in the accretionary prism accommodate two different types of submarine weathering processes: (i) Dissolution of reactive silicate minerals with concomitant transformation of CO_2 from methanogenesis into bicarbonate and (ii) alteration of silicate minerals and volcanic ash to smectite, which is accompanied by consumption of water thus leading to elevated pore water salinities.
Pore waters on the upper slope are characterized by negative chloride anomalies, which likely results from upward transport of clay dehydration fluids along splay faults. Thermal constraints from heat flow modeling suggest that these fluids originate in the overriding plate whereas dehydration of underthrust sediments seems to take place further seaward below the accretionary prism.

Slow Slip and Tremor at the Costa Rica Margin and Comparisons With Other Subduction Zones

Susan Y. Schwartz

Department of Earth and Planetary Sciences, University of California, Santa Cruz, CA 95060, USA

The discovery of slow slip and tremor has fundamentally changed our notions of how strain is released at plate boundaries and with it our assessment of their seismic hazards. While the last decade has witnessed an explosion in slow slip and tremor research, there are still some very important issues that remain unresolved. Whether tremor always accompanies slow slip, whether slow slip triggers increased seismicity, the role of fluids in slow slip and tremor generation, if slow slip and tremor are mostly restricted to the down-dip edge of the seismogenic zone or commonly occur at the up-dip edge or at other locations on the plate interface are all unknown. Regardless of the answers to these questions, we do know that slow slip is capable of triggering failure elsewhere on the fault that is fast enough to generate seismic waves. This seismic slip ranges from being unusually slow (low frequency and very low frequency earthquakes) to normal earthquake speeds. Intrinsic characteristics of the fault, such as frictional properties, control the mode of seismic slip and thus slow slip phenomena provide a new avenue into understanding the mechanical behavior of plate boundary faults. This talk will emphasize characteristics of slow slip and tremor at the northern Costa Rica margin and compare them with subduction zones globally. The temporal and spatial distribution of more than 5 years of tremor at the Nicoya Peninsula, Costa Rica reveals that some degree of slow slip occurs continuously, both at the edges and within the seismogenic zone, rather than only at the down-dip edge as reported in most other environments. Tremor locations are anti-correlated with normal earthquakes providing support to the contention that they represent unique frictional properties and thus mechanical behavior of the plate interface. If the occurrence of slow slip and tremor requires a transition in frictional properties from velocity weakening to strengthening, then tremor locations may be used to indicate where these frictional transitions occur within the seismogenic zone and thus the likely locations of maximum slip in future earthquakes.

Dispersed Volcanic Ash in Sediment entering NW Pacific Ocean Subduction Zones: Towards a Regional Perspective.

R.P. Scudder, R.W. Murray, Boston University, Boston, MA
M.B. Underwood, University of Missouri-Columbia, Columbia, MO
S. Kutterolf, SFB 574, GEOMAR, Kiel, Germany
T. Plank, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York

Volcanic ash has long been recognized to be an important component of the global sedimentary system. Ash figures prominently in a number of sedimentary and petrophysical investigations, including how the fluid budget of subducting sediment will be affected by hydration/dehydration reactions. Additionally, many studies focus on discrete ash layers, and how to link their presence with volcanism, climate, arc evolution, biological productivity, and other processes. Less widely recognized is the ash that is mixed into the bulk sediment, or “dispersed” ash. Dispersed ash is quantitatively significant and is an under-utilized source of critical geochemical and tectonic information.
Based on geochemical studies of ODP Site 1149, a composite of DSDP Sites 579 & 581, as well as IODP Sites C0011 & C0012 drilled during Expedition 322, we will show the importance of dispersed ash to the Izu-Bonin-Marianas, Kurile-Kamchatka and Nankai subduction zones. Initial geochemical analyses of the bulk sediment, as related to dispersed ash entering these subduction systems are presented here. Geochemical analysis shows that the characteristics of the three sites exhibit some variability consistent with observed lithological variations. For example, the average SiO_2/Al_2O_3 ratios at Site 1149, Site C0011 and Site C0012 average 3.7. The composite of Sites 579 & 581 exhibits a higher average of 4.6. There are contrasts between other key major elemental indicators as well (e.g., Fe_2O_3). Ternary diagrams such as K_2O-Na_2O-CaO show that there are at least two distinct geochemical fields with Sites 1149, C0011 and C0012 clustering in one and Sites 579 & 581 in the other. Q-mode Factor Analysis was performed on the bulk sediment chemical data in order to determine the composition of potential end members of these sites. The multivariate statistics indicate that Site 1149 has 3-4 end members, consistent with the results of Scudder et al. (2009, EPSL, v. 284, pp 639), while each of the other sites has 4-5 end members. These geochemical signatures (e.g., K_2O) of the dispersed ash can be exploited to provide insight into the importance of clay mineralogy (i.e., smectite). Additional results from trace and REE analyses, combined with additional statistical treatments, will also be presented.

General geochemical trends and local compositional diversity in the SVZ

Daniel Selles

Santiago, Chile

The Southern Volcanic Zone exhibits substantial along strike variations both in the setting of the volcanoes and the nature of its products. Volcano elevation decreases progressively southwards in correspondence to decreasing Bouguer gravity anomaly, underlying crustal thickness, and subducted slab age in the same direction. The most northerly portions of the SVZ, where the crust is probably >60 km thick, is the classic region that provided the evidence for the MASH hypothesis that crustal processes irrevocably obscure the subduction signal. Further south the crust is thinner and varies less markedly with latitude, crustal overprint is less strong but still has been proposed on the basis of trace element systematics as well as detailed studies.
Concurrently with the publication of the MASH hypothesis, Plank and Langmuir (1988) concluded that global chemical variability including continental arcs can be related to extents of melting in the mantle wedge, since thicker crust and mantle lithosphere result in a smaller and deeper mantle melting column. The result is lower degrees of melting occurring on average at deeper levels, reflected, for example by higher $Na_{6.0}$.
Both approaches have been used, not without controversy, in studies seeking to explain compositional variations in magmas along the SVZ, putting emphasis on mantle melting or crustal overprint as the main control.
Detailed studies comparing neighboring volcanic centers, or large stratovolcanoes to surrounding minor eruptive center fields, or even concerning sequences of varying age in one location, where major geodynamic parameters are not expected to vary substantially, can provide important clues to evaluate the relative importance of large-scale setting and local geological factors in the final geochemical signal of erupted magmas.

Unusual Fault Pattern and Abundant Gas and Fluid Venting off Southern Costa Rica, Along the Trajectory of the Subducting Quepos Ridge

Eli Silver, Jared Kluesner, and James Gibson, Earth and Planetary Sciences, University of California, Santa Cruz, CA
Nathan Bangs and Kirk McIntosh, University of Texas, Austin, TX
Roland von Huene, University of California, Davis, CA
Cesar Ranero, Barcelona Center for Subsurface Imaging, Barcelona, Spain

We have carried out a multibeam and backscatter study of part of the southern Costa Rica margin in conjunction with a 3D seismic experiment, using the EM122 system aboard the R/V Marcus G. Langseth. Ship line spacing of the 3D seismic data was 150 m, which allowed us to acquire the multibeam and backscatter data using constrained receiver beam spacing (fixed swath width), and for much of the survey we were able to record 9 to 10 fold overlap in water depths exceeding 255 m. This closely spaced method allows gridding at cell sizes much smaller than conventional mutibeam data (2-5 m grids for backscatter and 5-10 m grids for bathymetry), which allowed us to image multiple structures and abundant fluid and gas vent sites throughout this region, from the shelf to the lower slope. On the outer shelf we mapped a series of arcuate high and low backscatter layers, displayed because this part of the outer shelf has eroded the top of an anticline. The outermost 3-5 km (135-200 m water depth), a region not exposed during the last glacial period, is buried by a sediment drape. The folded layers are displaced by a dense system of faults, trending roughly N-S and E-W, and spaced an average of about 200 m apart, although spacing varies significantly from place to place. The faults show apparent horizontal displacement, but the sense of displacement is inconsistent, making it more likely that these are normal faults, not strike-slip faults. The shelf break, located approximately along the 250 mbsl contour is arcuate in shape, similar to erosional scars left by seamount subduction.
On the outermost shelf that is covered by young sediments we have mapped a number of pockmarks and mounds, varying in size from tens to hundreds of meters across. Large pockmarks are complex, with local mounds. Small features include pockmarks, mounds, and combinations of these (mounds with symmetrical or asymmetrical lows). At least one site has acoustic evidence of gas venting recorded in the 3.5 kHz data, and many of the surface indications of fluid-flow lie above reverse

polarity bright spots and flat spots in the shallow part of the seismic reflection data, commonly associated with the crests of anticlines. In numerous instances, lines of small pockmarks and mounds lie along fault traces seen in the 3D seismic volume. Some of these faults can be seen to continue into the basement beneath the sedimentary section. On the slope, such lines of pockmarks often lie along narrow submarine channels, likely controlled by faulting, although not all pockmarks and mounds are associated with sediment drainage. In the mid-slope region, a major zone of surface and subsurface fluid-flow indicators occurs at the updip edge of the BSR, suggesting a relationship between the lack of gas hydrate and the efflux of gas through to the seafloor. The abundant gas and fluid-flow indicators that we have mapped and the great detail to which we can image faulting could be the result of seamount or ridge collision and extraordinary fracturing of the continental margin rocks, or they could indicate that acquisition of multibeam data with very high sounding densities and signal-to-noise ratio allows us to obtain this spectacular view of the margin structure. Because a number of other seamount traces are present along this margin, we feel that the latter explanation provides the opportunity to gain a much more in-depth understanding of the processes occurring on active margins.

SFB 574 Data Management

Pina Springer

SFB 574, GEOMAR, Kiel, Germany

The SFB 574 data management is part of the Kiel Data Management Infrastructure (KDMI), a joint data management approach for SFB574, SFB754, the cluster of Excellence ‚Future Ocean' and the Helmholtz Centre for Ocean Research Kiel (GEOMAR). The KDMI set up a portal (portal.geomar.de) where SFB members collect and share research data with a set of meta information in the context of cruises, expeditions and model experiments. Additional information like related links to print and online publications, data repositories and the drill core repository are available. All information can be visualized with automatically generated Google Earth files. Because data from publicly funded research projects should be available to the public when the project has been completed, all published data are transferred to World Data Centres for long term availability.

Response and efficiency of the benthic microbial methane filter under non-steady state conditions

Steeb, P., Kretschmer, K., Linke, P., Treude T.

SFB 574, Helmholtz-Centre for Ocean Research (GEOMAR), Kiel

The microbial benthic methane filter of the ocean floors globally retains approximately 80-90% of the ascending greenhouse gas methane through anaerobic oxidation of methane (AOM). However natural and catastrophic fluctuations of methane fluxes (caused e.g. by gas hydrate melting, earthquakes, slope failure) can challenge the capability of this greenhouse gas sink. We ask: How efficient can the methanotrophic community adapt its activity to methane flux changes, what is its response time and what is the efficiency of the benthic filter in this time.
To answer these questions, a new sediment-flow-through-system was developed. The system holds intact sediment cores and simulates natural condition of seepage with a diffusive supply of sulfate from the top and an advective transport of methane from the bottom. Sampling holes allow monitoring the key parameters (sulfate, sulfide, pH, Redox, Total Alkalinity) over the entire sediment depth.
For our experiments, sediment from three different methane-rich environments were used: (1) gassy sediments from Eckernförde Bay (German Baltic) without naturally occurring advective fluid transport, (2) sediments with high advective transport from a methane seep within an oxygen minimum zone on the continental margin (Quepos Slide, Costa Rica), and (3) methane-seep sediments from the center of a mud volcano (North Alex Mud Volcano, Eastern Mediterranean Sea). Two different advective methane flow rates (15.3 and 153 mmol CH_4 $cm^{-2}yr^{-1}$, fluid flow 10.9 and 109 cm yr^{-1}) were applied for replicate sediment cores (upper 20cm) of the respective environments. The poster will present results of the long-term experiment and compare the response of the different sediment types to the varying methane and fluid flow rates.

Using biomarkers in carbonates to study microbial methane turnover at cold seeps

Volker Thiel

Geobiology Group, Geoscience Centre, University of Göttingen, Göttingen, Germany

Cold seep carbonates consist of complex assemblages of microbially mediated mineral precipitates, with a geological record back to the Mid-Palaeozoic. However, even in subrecent deposits the linkage between the different mineral phases and methanotrophic organisms involved in their precipitation is difficult to establish. In my talk I will outline how lipid biomarkers can be utilized as tracers to resolve methane-fueled biogeochemical processes archived in seep deposits. Late Pleistocene seep carbonates retrieved during RV SONNE cruise SO-210 off Chile were studied using a miniaturized lipid biomarker approach, and stable carbon isotopes of carbonates as well as of individual biomarker compounds were analyzed. Constantly low $\delta^{13}C$ values indicate a methane source for the carbonate carbon from all phases. The major part of the inherited biomarker signal, however, is concentrated in distinctive aragonite phases that make up a quantitatively minor portion of the bulk rock. Specific, strongly ^{13}C-depleted lipids related to the anaerobic oxidation of methane (AOM) suggest that the aragonite represents fossilised biofilms that once harboured mainly methanotrophic archaea of the phylogenetic ANME-2 group. Other carbonate cements, consistently lean in biomarkers, likely precipitated without an immediate spatial association with AOM microorganisms. Observations made for further (sub-)recent (Hydrate Ridge) and ancient (Lincoln Creek Formation, Oligocene) seep localities revealed similar trends and suggest consistent mechanisms of seep carbonate formation over geological times.

Non-volcanic tremor in Costa Rica: b-values, moment release and tidal modulation

Thorwart M, Rabbel W

SFB 574, Institute for Geosciences, University of Kiel, Germany

In the Central American subduction zone non-volcanic tremor (NVT) events have been recorded on Nicoya Peninsula (N Costa Rica) since July 2006 by using an array of short period borehole seismometers. NVT hypocenters locate between 30 and 45 km depth near the interface of the subducting Cocos and overriding Caribbean plates. They form a depth continuation of the seismogenic zone. We present the results of a statistical analysis of the time series of NVT events recorded continuously over the past 5 years. Using tremor time duration as a measure of their magnitude we found that different scaling laws apply to different phases of NVT activity. Bursts (swarms) of NVT events follow a Gutenberg-Richter type of law with a b-value of 1 if the cumulative tremor duration of each burst is converted to seismic moment and earthquake magnitude by application of corresponding empirical constants found for the Cascadia subduction zone (e.g. Wech et al., 2010). However, the time length of single tremors follows a different statistics. It cannot be characterized by a Gutenberg-Richter type relation but can be represented by two pairs of a,b-values and a "corner duration time". These characteristic constants are different for the time intervals of bursts and between bursts. This difference in the statistical behavior can possibly be explained by tidal forcing of the tremor activity during burst phases: It was found that about 2/3 of the NVT events belonging to bursts coincide with tidal stress maxima whereas no such correlation could be identified for the time intervals between bursts.

The climate impact of the Young Toba Tuff eruption: An Earth System model approach eruption

C. Timmreck

Max-Planck-Institut für Meteorologie, Hamburg, Germany (claudia.timmreck@zmaw.de)

Climatic impacts of the Younger Toba Tuff (YTT) eruption about 73 ka yr ago are a crucial argument in the current discussion about the fate of modern humans especially in Africa and Asia. We use Earth system model (ESM) simulations to investigate the climate impacts of the YTT eruption focusing

in particular on those areas which were relevant to human evolutionary issues during that time. Information about transient changes in vegetation types after the eruption are obtained by forcing an offline dynamical global vegetation model with simulated climate anomalies from the ESM under both glacial and interglacial background climate conditions. The simulated temperature changes in those areas that were inhabited by humans at the time of eruption suggest thermal discomfort, but not a real challenge. Precipitation is reduced in all regions during the first two years but recovers quickly thereafter. Some catchments (Ganges/Brahmaputra, Nile), experienced an over-compensation in precipitation during the third to fifth post-eruption years which is also reflected in anomalously strong river runoffs. Change in vegetation composition may have created the biggest pressure on humans, who had to adapt to more open space with fewer trees and more grasses for some decades, especially in the African regions. The strongest environmental impacts of the YTT eruption are simulated under interglacial conditions suggesting that the climate effects of this eruption did not impact humans on a major scale and for a period long enough to have dramatic consequences for their survival.

The Influence of Eruption Season on the Global Aerosol Evolution and Radiative Impact of Tropical Volcanic Eruptions

Matthew Toohey (1), Kirstin Krüger (1), Ulrike Niemeier (2), Claudia Timmreck (1,2)

(1) SFB 574, GEOMAR, Kiel, Germany
(2) MPI-M, Hamburg, Germany

Simulations of tropical volcanic eruptions carried out with a general circulation model with coupled aerosol microphysics are used to assess the influence of season of eruption on the aerosol evolution and radiative impacts at the Earth's surface (Toohey et al., 2011). This analysis is presented for eruptions with SO_2 injection magnitudes of 17 and 700 Tg, the former consistent with estimates of the 1991 Mt. Pinatubo eruption, the later with estimates of the Los Chocoyos eruption of 84 ka BP from modern-day Guatemala. For each eruption magnitude, simulations are performed with eruptions at the location of the Los Chocoyos eruption site (15° N, 91° W) at four equally spaced times of year. Sensitivity to eruption season of aerosol optical depth (AOD), clear-sky and all-sky shortwave (SW) radiative flux is quantified based on the difference between the maximum and minimum response from the four eruption seasons. Eruption season has a significant influence on AOD and clear-sky SW radiative flux anomalies for both eruption magnitudes, reaching maximum values of ~75 %. All-sky SW anomalies are found to be sensitive to season of eruption for the Los Chocoyos eruption magnitude, but insensitive to season of eruption for the Pinatubo-magnitude eruption experiment. Our estimates of sensitivity to eruption season are larger than previously reported estimates: implications regarding volcanic AOD timeseries reconstructions and their use in climate models are discussed.
Reference: Toohey, M., Krüger, K., Niemeier, U., and Timmreck, C.: The influence of eruption season on the global aerosol evolution and radiative impact of tropical volcanic eruptions, Atmos. Chem. Phys., 11, 12351-12367, doi:10.5194/acp-11-12351-2011, 2011.

Biogeochemical characterization of newly discovered seeps in the Concepción Methane Seep Area, Chile

T. Treude, P. Steeb, P. Linke, F. Scholz, M. Schmidt, V. Liebetrau

SFB 574, Helmholtz-Centre of Ocean Research (GEOMAR), Kiel, Germany

Within subduction zones of active continental margins, large amounts of methane can be mobilized by dewatering processes and transported to the seafloor along migration pathways. The recently discovered Concepción Methane Seep Area (CMSA, water depths between 600 to 1100 mbsf) is characterized by active methane vent sites as well as massive carbonates boulders and plates which probably are related to methane seepage in the past. During the SO210 research expedition “Chiflux” (Sept-Oct 2010), sediment from the CSMA at the fore arc of the Chilean margin was sampled to study microbial activity related to methane seepage. We sampled surface sediments (0-30cm) from sulfur bacteria mats, as well as clam, pogonophoran, and tubeworm fields with push cores and a TV-guided multicorer system. Anaerobic oxidation of methane (AOM) and sulfate reduction rates were determined using ex-situ radioisotope tracer techniques. Additionally, porewater chemistry of retrieved

cores as well as isotopic composition and age record of surrounding authigenic carbonates were analyzed. The shallowest sulfate-methane-transition zone (SMTZ) was identified at 4 cm sediment depth hinting to locally strong fluid fluxes. However, a lack of Cl- anomalies in porewater profiles indicates a shallow source of these fluids, which is supported by the biogenic origin of the methane ($\delta^{13}C$ -70‰ PDB). Sulfide and alkalinity was relatively high (up to 20 mM and 40 mEq, respectively). Rates of AOM and sulfate reduction within this area reached magnitudes typical for seeps with variation between different habitat types, indicating a diverse methane supply, which is affecting the depths of the SMTZ. Rates were highest at sulfur a bacteria mats (20 mmol m^{-2} d^{-1}) followed by a large field of dead clams, a pogonophoran field, black sediment spots, and a carbonate rich clam field. Lowest rates (0.2 mmol m^{-2} d^{-1}) were measured in close vicinity to these hot spots. Abundant massive carbonate blocks and plates hint to a very old seep system with a probably much higher activity in the past. The U-Th age record of these authigenic carbonates reach back to periods of venting activity with more than 150 ka ago. Carbon isotopic signatures of authigenic carbonates ($\delta^{13}C$ -50 to -40 ‰ PDB) suggest a biogenic carbon source (i.e. methane), also in the past. We found several indications for the impact of recent earthquakes within the seep area (cracks, shifted seafloor), which could be an important mechanism for the triggering of new seepage activity, change in fluid expulsion rates or colonization patterns of the cold seep fauna.

CRISP A expeditions: synthesis of key results from IODP Exp. 334 and an introduction to IODP Exp. 344

Paola Vannucchi

Dept. Earth Sciences, University of Florence, Italy

IODP Expedition 334 took place in Spring 2011 offshore the Osa Peninsula in the Costa Rica subduction zone. This drilling expedition represented the beginning of the Costa Rica Seismogenesis Experiment (CRISP), a multi-year project aiming at exploring the processes responsible of earthquake nucleation and rupture propagation along erosive plate boundaries. During IODP Exp. 334 we obtained a comprehensive suite of data at the three upper and middle slope sites which were focused on the up-dip transition from seismic to aseismic plate boundary fault behavior, using logging while drilling (LWD) techniques and coring to depths of 450 to 950 m. A site was also devoted to drilling and coring the incoming Cocos Ridge. One highlight of LWD and core results is evidence for the orientation of present-day principal stresses from borehole breakouts, and paleostresses from fractures and faults in cores. The orientation of the maximum horizontal stress axis (SH_{max}) from breakouts changes from NNW-SSE in the middle slope to ENE-WSW in the upper slope site, consistent with a compressional to transpressional stress state in the outer wedge according to Cocos Ridge indentation, and an extensional state of stress in the inner wedge. Coring in the upper slope reached the forearc basement as defined by geophysical techniques. Biostratigraphy marked the oldest silty/clayey slope sediments, drilled at ~ 900 mbsf, as being deposited at the Plio/Pleistocene boundary (~2.2 Ma), which indicates very high sedimentation rates up to 1035 m/my. Onland uplift triggered by Cocos Ridge subduction can easily provide this material, while the processes leading to such strong forearc subsidence can be associated with subduction erosion and upper plate thinning. Both of these processes can be also linked to the landward dipping fractures/normal faults visible in seismic images, which are also characterized by localized fluid flow as revealed by shipboard geochemical data.
CRISP will go back to drill in the Fall 2012 through IODP Exp. 344. Expected results include: a) new constraints on timing and evolution of subsidence, b) continuous structural and physical property logs to better constrain the stress and strain history of forearc material, c) dècollement penetration at the toe of the margin.

Heat flow in the Southern Chile Forearc controlled by large-scale tectonic processes

Lucia Villar-Muñoz[1], Juan Diaz-Naveas[2], Jan H. Behrmann[1]

[1] GEOMAR, Helmholtz-Zentrum für Ozeanforschung, D-24148 Kiel, Germany
[2] Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile

From north to south, the Southern Chile forearc is affected by the subduction of the aseismic Juan Fernandez Ridge, a number of major oceanic fracture zones on the downgoing Nazca Plate, the active Chile Ridge spreading center, and underthrusting of the Antarctic Plate. The tectonic structure is characterized by intense deformation of the lower continental slope within a variably wide accretionary wedge. In places the middle and upper slope is affected by out-of-sequence overthrusting and by normal faulting. In the area of the Chile Triple Junction at 46°S latitude most of the forearc is destroyed by subduction erosion, to be rebuilt further south by sediment offscraping and accretion from the Antarctic Plate.
The Southern Chile forearc has been intensively explored by reflection seismic surveys, and has been drilled by the Ocean Drilling Program during two expeditions (ODP Leg 141 - Behrmann et al., 1992; ODP Leg 202 – Mix et al., 2003). The widespread occurrence of gas hydrates has been known for some time. Regarding the analysis of reflection seismic sections we have used data of R/V SONNE Expeditions 101 and 161, R/V VIDAL GORMAZ Expeditions VG02 and VG06, and R/V ROBERT CONRAD Cruises RC2901 and RC2902. Using bottom water temperature data obtained from the World Ocean Data Base (NOAA) and an acoustic velocity model constrained from the seismic sections, and measurements of temperature, thermal conductivity and acoustic velocity from ODP boreholes, we use the position of the Bottom Simulating Reflector (BSR) in reflection seismic sections to estimate the heat flow through the forearc in an area between 32°S and 47°S latitude.
Heat flow in most of the upper and middle continental slope is on the order of 50-80 mWm^{-2}. This is normal for continental basement and overlying slope sediments, and is true also for those parts in the south of the area that are being underthrusted by hot, young oceanic crust. The middle and lower slopes, however, in some places display up to 50% increased heat flow. Here the sea floor is underlain by zones of active deformation and accretionary wedge building. This observation cannot be easily reconciled with models of conductive heat transfer, but is an indication that advecting pore fluids from deeper in the subduction zone may transport a substantial part of the heat there. The size of the anomalies indicates that fluid advection and outflow at the sea floor is diffuse rather than being restricted to individual fault structures, or mud volcanoes and mud mounds, as is the case in other convergent margins.
A large area with higher heat flow correlate in space with tectonic phenomena, however. On the lower slope above the subducting Chile Ridge at 46°S, values of up to 280 mWm^{-2} indicate that the overriding South American Plate is effectively heated by subjacent zero-age oceanic plate material on a regional scale.

References

Behrmann, J.H., Lewis, S.D., Musgrave R., et al. (1992) Proceedings of the Ocean Drilling Program, Initial Reports, 141. Ocean Drilling Program. College Station, TX
Mix, A.C., Tiedemann, R., Blum, P., et al. (2003) Proceedings of the Ocean Drilling Program Initial Reports, 202. Ocean Drilling Program, College Station, TX.

Tectonic control on submarine mass wasting off Central Chile

David Völker, Jacob Geersen, Willi Weinrebe, JH Behrmann

SFB 574, GEOMAR | Helmholtz Centre for Ocean Research, Wischhofstr. 1-3D-24148 Kiel, Germany

Submarine landslides are an important but underestimated geological hazard. They can destroy offshore installations like cables and oil platforms, and generate destructive tsunamis that can devastate populated shorelines regionally. Off Central and Southern Chile more than 60 submarine landslides were identified based on a unique bathymetric dataset that was continuously extended and refined over 16 years and 16 scientific cruises and that now covers ~ 90% of the continental margin. Despite of the good documentation, still little is known about the mechanisms that caused the individual slope failure events, about the frequency of such events and their relation to the powerful earthquakes that happen here each 50-100 years.

To investigate the preconditioning and triggering mechanisms for the landslides we combine the high resolution swath bathymetric data set with reflection seismic profiles and sediment-echosounder data. In particular we focus on how the tectonic regime, that significantly varies along-strike, impacts on the type, shape and frequency of slope failures. Furthermore, we investigate how the direct and instantaneous seismic loading generated by the magnitude 8.8 Maule Earthquake that ruptured parts of the study area on the 27 February of 2010 impacted on the slope stability. Such a comparison is possible as we mapped the rupture area bathymetrically before and shortly after the earthquake.
Our results indicate that the spatial occurrence of two groups of landslides - lower slope collapses and failures that affect the entire slope - are closely related to the tectonic segmentation of the forearc, and that the long-time tectonic stress regime is a major factor preconditioning slope failure. The seismic loading by the Maule earthquake, on the other hand had surprisingly little effect in triggering km-size submarine landslides, albeit steep slopes, ubiquiteous mass wasting of the past and extreme vertical acceleration in the rupture area.

Multi-scale volcano deformations in the Andes observed by InSAR

Thomas R. Walter

Volcano Tectonics Research Group, GFZ German Research Centre for Geosciences, Potsdam, Germany

We generated a decade long InSAR time series to investigate the spatiotemporal characteristics of volcanoes in the central Andes. The data reveal different scales of deformation at volcanoes. For instance, we identify a large-scale uplift at the Lazufre system that started in 1997 with an increase of the mean uplift rate of up to 3.2 cm/yr, now affecting several eruptive centers situated in an area larger than 1800 km^2. Moreover, the same region is affected by more small-scale volcano deformations such as localized uplift at the Lastarria volcano, with most of the clear deformation apparently not observed before 2000. Both the large and small uplift signals can be explained by magmatic or hydrothermal sources located at about 13 km and 1 km deep, respectively. Residual analysis shows even more local scale deformation processes occurring such as multiple landslides and deformation of salar surfaces, indicating a number of complex and potentially mutually interacting geologic phenomena such as deep intrusions, shallow volcanic sources, gravitational displacements and hydrogeologic effects.

On the probability of future plinian eruptions at the Central American Volcanic Arc: a statistical time series analysis

Heidi Wehrmann[1], Yvonne Dzierma[2], Steffen Kutterolf[1], Theresa Schaller[2]

[1] SFB 574, GEOMAR, Kiel, Germany
[2] SFB 574, Institute of Geosciences of the University of Kiel, Germany

Plinian eruptions belong to the most devastating types of volcanic activity, thus posing a dramatic hazard for people and property far beyond the immediate surroundings of a volcano. Assessing volcanic hazards consists of a number of aspects. First, detailed isopach and isopleth mapping of past eruptions' deposits facilitates to constrain typical eruption behaviour in terms of eruption magnitudes, intensities, and affected areas. The second component integrates a variety of surveillance techniques, including seismic recording, compositional and thermal monitoring of quiescent gas emissions, ground deformation, etc. In many cases such monitoring efforts can signal that a volcano is building up towards an eruption, and may allow for a timely alert and mitigation actions. In addition to the knowledge on expected consequences an eruption might entail, and to the recording of physical processes, the hazard and risk evaluation strongly depends on the likelihood that an eruption may happen. It is therefore of pivotal interest to understand the chronological character of a volcano or a volcanic area. Statistical time series analyses of eruption records provide a powerful tool for meeting the growing demand for probabilistic eruption forecasting.
The Central American Volcanic Arc (CAVA) has been site of numerous exceptionally explosive and voluminous plinian eruptions over the past 200 000. We here process the long-term plinian eruption record of the subduction system by statistical means, considering felsic and mafic eruption sequences

separately. After ensuring that the necessary conditions for the analysis are fulfilled, the Kaplan-Meier method is applied to estimate survival functions. Subsequently, the exponential, the Weibull, and the log-logistic distribution are fit to the data. All functions are confirmed by goodness-of-fit tests to describe the data sets adequately well. Future eruption probabilities within a given time interval are then estimated from the survivor functions. The likelihood that a large plinian eruption will occur at the CAVA within the next ~100 years is 5-8 %, and the 50 % probability is reached within ~1300 years. These results are nearly identical for a felsic plinian eruption or an eruption of any composition. Mafic plinian eruptions are less likely to occur, their probability to happen within ~100 years amounts to 1 %, while the 50 % and 100 % probability is reached in ~6,000 and ~50,000 years, respectively. Compared to the felsic plinian eruptions, this latter result may seem relatively reassuring – but in the context of the worldwide record, in which plinian eruptions of mafic compositions are extremely scarce and still considered exotic, it is a high probability. As an unusually common phenomenon at the CAVA, we emphasise the importance to adequately consider mafic plinian eruptions in the course of comprehensive volcanic hazard assessment.

On the fluid-mobility of molybdenum, tungsten, and antimony in subduction systems

H. Wehrmann[1] , R. Halama[2], D. Garbe-Schönberg[2], K. Hoernle[1], G. Jaques[1], K. Heydolph[1], J. Mahlke[1], K. Schumann[1]

1 SFB 574, GEOMAR, Kiel, Germany
2 SFB 574, Institute of Geosciences of the University of Kiel, Germany

Molybdenum (Mo) and tungsten (W) have long been regarded as being more or less immobile during slab fluid-induced arc magma generation. Here we characterize about 180 samples of young, predominantly mafic to intermediate tephras and lavas for their Mo, W, and antimony (Sb) concentrations, to examine the fluid-mobility of these elements in subduction systems. Samples were taken along the active arcs of the Chilean Southern Volcanic Zone (SVZ) and the Central American Volcanic Arc (CAVA). When relating Mo, W, and Sb to trace element ratios typically used to constrain the involvement of subduction fluids in magma formation, such as Ba/La or U/Th, Mo, W, and Sb are enriched in the most fluid-influenced, highest-degree melts. W/Mo ratios correlate positively with Pb/Ce, which is established to reflect a recent subduction signal or assimilation of crustal material with an ancient subduction signature, suggesting that subduction processes promote enrichment of W over Mo. This is well expressed at the SVZ and most of the CAVA; while few OIB-type rocks from Central Costa Rica form an opposite trend. Moreover, Mo/W ratios co-vary with Cl contents derived from melt inclusions, indicating that the relative degree of mobilization responds to the composition of the subduction fluid.
To evaluate the mobility of Mo, W, and Sb during metamorphism in the slab, eclogites with no or minor metasomatic overprint and a fluid-induced overprint in an eclogite-blueschist sequence were investigated. None of the three elements shows a systematic variability related to metasomatism and the minor variations are interpreted to reflect protolith heterogeneity. This suggests that Mo, W and Sb remain relatively immobile up to depths of 70 km in the subduction zone.

Sulphur and chlorine geochemistry of mafic to intermediate tephras from the Chilean Southern Volcanic Zone (33-43°S) compared with those from the Central American Volcanic Arc

Heidi Wehrmann[1], Kaj Hoernle[1], Guillaume Jacques[1], Dieter Garbe-Schönberg[2], Kai Schumann[1], Julia Mahlke[1], Luis Lara[3]

[1] SFB 574, GEOMAR Helmholtz Centre for Ocean Research Kiel, Wischhofstr. 1-3, 24148 Kiel, Germany
[2] SFB 574, Institute of Geosciences, University of Kiel, Ludewig-Meyn-Str. 10, 24118 Kiel, Germany
[3] Sernageomín (Servicio Nacional de Geología y Minería), Av. Santa María 0104, Santiago, Chile

Here we present the first systematic investigation of volatile geochemistry along the Southern Volcanic Zone (SVZ) of Chile. Holocene olivine-hosted melt inclusions in the most mafic tephras sampled from 16 volcanoes along the volcanic front of the SVZ were analysed for pre-eruptive sulphur, chlorine and major element contents. These results are combined with trace element

compositions of the host whole rocks. The highest fractionation-corrected gas contents occur in the least-degassed melt inclusions from small peripheral cones from both the transitional and the southern-central SVZ, reaching ~3000 µg/g S and 1400 µg/g Cl, while the lowest abundances of ~1000 µg/g S and ~600 µg/g Cl were found in the central SVZ at Volcán Lonquimay, Volcán Llaima, and Volcán Villarrica. Chlorine co-varies with trace element indicators for the degree of melting and/or source enrichment. The highest Cl enrichment is present in the melts with least degree melting, underscoring its incompatible behaviour. The lowest Cl contents are found in high-degree melts from the most depleted mantle sources. The size of the volcanic edifices correlates inversely with Cl abundances in the melt.

In comparison with other subduction zones, the SVZ melt inclusions exhibit Cl abundances in the same range as most of those from the Central American and those from the Marianas arcs. In contrast, S concentrations are lower at the SVZ, with the exception of small peripheral cones of Los Hornitos next to Cerro Azul, Cabeza de Vaca near Osorno, and Apagado. The lower S contents are likely to be related to the generally more evolved nature of the SVZ lavas, compared to those from Central America and the Marianas.