lower sedimentary layer has P-wave velocity of 2.0 - 3.5 km/s with relatively large vertical velocity gradient. The thickness of the lower layer has large variety from 800 m to 3500 m. The upper crust is large lateral heterogeneity and is also divided into two layers. Velocity at the top of the upper crust vary from 3.0 - 4.9 km/s. The lower layer of the upper crust has velocity of 5.6 - 6.0 km/s. The thickness of the upper crust changes from 3 km to 9 km. The boundary between the upper crust and lower crust is about 10 km deep below the sea surface. The lower crust has velocity of 6.5 - 6.7 km/s. Compared with the upper crust, the lower crust is relatively homogeneous. A thickness of the lower crust is about 15 km. The crust has a thickness of about 25 km in total and the Pn velocity is estimated to be 7.7 -7.8 km/s.

The distribution of the P-wave velocity and the thickness of the crust indicates that the crust of the northernmost part of Okinawa Trough is similar to that of an island arc than to that of an ocean. The obtained seismic structure suggests that the northernmost part of the Okinawa Trough is in the incipient stage of the back-arc rifting.

T52B MC: Hall D Friday 1330h

Syn-Convergent Extension in the Apennines, Italy II *(joint with G, S, V)*

Presiding: **S Willett,** University of Washington

T52B-0928 1330h INVITED POSTER

Quantifying Exhumation History Across the Northern Apennines

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Exhumation of Northern Apennines has been investigated through low-temperature geochronometric data (apatite fission-track analysis, AFT; U-Th/He on apatite and zircon). Results show a different thermotectonic evolution for the drainage divide area (Mt. Falterona, MF) and the metamorphic complex of the Apuane Alps (AA) on the Tyrrhenian side. Throughout the late Middle and Late Miocene, the AA were exhumed at a constant rate of 1.5 mm/y, whilst the MF area was rapidly subsiding, buried by foreland turbidites and eventually by the Ligurian unit. Exhumation in the AA abruptly dropped to 0.5 mm/y at the Early Pliocene. At that time, the MF started to be exhumed at a rate of 0.7 mm/y. No evidence for pronounced topography exists. With those rates, erosion could keep the pace with uplift. From Middle Pliocene onward, coarse-grained sedimentation in intramontane basins documents growing relief, with the final development of the present-day topography. The uplift rates increased to values of 1.4 mm/y in the MF and 0.8 mm/y in the AA. The MF became the most elevated area, therefore creating the present watershed.

T52B-0929 1330h POSTER

Time to Steady State in Emergent Convergent Wedges: Olympic Mountains of the Washington Cascadia Margin, and the Apennines of Northern Italy

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The Olympic Mountains of NW Washington State and the Apennines of Northern Italy show a similar history in their emergence and transition to a flux steady state. The Olympics represent the forearc high of the Cascadia subduction wedge; the Juan de Fuca plate is subducting at ∼35 km/m.y. beneath this wedge, driving accretion of a 2-3 km thick sedimentary cover. The modern accretionary flux is ∼63 km^2/m.y, which is similar to the long-term erosional outflux of ∼51 km^2/m.y. Cooling ages show steady erosion rates from the core of the orogen over the last 14 m.y., indicating a flux steady state, where the accretionary and erosional fluxes are equal. What is remarkable is that the Olympics came into a flux steady state within 4 m.y. after initial emergence above sea level. The Olympic sector of the Cascadia wedge is currently 230 km wide and 30 km deep at its thickest point, equal to a cross section of 3450 km^2. If the wedge reached its present steady state size solely by accretionary growth, it would have had to increase its cross section by 1055 km^2, which implies a growth rate of >264 km^2/m.y. given the <4 m.y. time for transition to a flux steady state. This flux is too fast to be drive by accretion alone. Some other process must be involved.

In comparison, the Apennines convergent wedge has formed by subduction of thinned continental crust of the Adriatic plate. Convergence rates are slower, at ∼4 to 5 km/m.y. since 30 Ma. The accreted sedimentary cover, however, is much thicker, ∼12 km, which gives an accretionary flux of ∼40 to 50 km^2/m.y. Integration of erosion rates across the orogen indicate an erosional outflux of ∼40 km^2/m.y. This balance between accretionary and erosion fluxes is consistent with fission-track and He cooling ages that indicate steady erosion rates in the core of the orogen, starting at ∼5 Ma. Like the Olympics, the onset of steady state seems to have occurred shortly after emergence at ∼5 Ma, and at fast rates, inconsistent with growth by accretion alone.

In the both the Olympics and the Apennines, some process other than accretion is needed to account for a fast transition to a flux steady state, following emergence of the wedge above sea level. Some have argued for slab breakoff as a mechanism to drive rapid uplift in the Apennines, but tomographic images show that the subducted slab is still present beneath the northern Apennines. I propose that in both cases, rapid uplift was caused by changes in the subducting plate. In the Olympics, there is good evidence that the present concave-outward shape of the trench formed at ∼15 Ma, in association with extension across the Basin and Range. This change caused an arch to form in the slab beneath the Olympics. For the Apennines, rapid uplift appears to be the result of the wedge overriding a passive margin ramp. Prior to 5 Ma, the Northern Apennine wedge was overriding highly thinned Adriatic crust (∼7 km thick below the accreted sedimentary cover), whereas now that equivalent crustal section is ∼22 km thick.

T52B-0930 1330h POSTER

Numerical Modeling of Continental Subduction in Apennines-Style Context

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We performed numerical experiments of early stages of continental subduction and slab detachment at the mantle scale, using a 2D thermo-mechanical model which accounts for brittle-elasto-ductile behaviour and for surface processes.

Our goal is to study the influence of various parameters on subduction-related orogens (for instance the Apennines) such as density contrasts, convergence rate, thermal state and intensity of surface processes.

The model reproduces the subduction cycle from early stages to penetration of the slab to the 660 km boundary. Depending of the parameters' combination, the evolution of the initiated slab varies from rapid detachment to stagnation of the subduction. An important feature of our experiments is the almost systematic occurrence of underplating of the lower plate crust beneath the upper plate, leading to formation of double-Moho like structures. It appears that the subducted upper crust and sediments may play a role of lubrification layer, like the low friction coefficients used in some previous models.

The results show that the main controlling parameter of slab evolution is the density contrast between the slab, subducted crust, and surrounding asthenosphere : for instance, when the contrast between the slab and the asthenosphere is larger than 0.02, the sinking rate of the slab is high, and slab detachment can occur within the first million years after onset of subduction. The rate of convergence appears to be a second-order parameter, a high rate being able to prevent detachment. The intensity of surface processes predominantly controls the surface topography, and also seems to be able to influence deep processes such as the sinking rate. Thus, the same topography can be maintained for completely different subduction scenarios.

T52B-0931 1330h POSTER

Extensional Structures on the Po Valley Side of the Northern Apennines

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The present-day tectonics of the Northern Apennines is characterized by extension in the inner Tyrrhenian side and compression in the outer Po Valley-Adriatic side. The boundary separating the two domains, extensional and compressional, is still largely undetermined and mainly based on geophysical data (focal mechanisms of earthquakes). Map-scale extensional structures have been studied only along the Tyrrhenian side of the Northern Apennines (Tuscany), while along the Po Valley-Adriatic area the field studies concentrated on compressional features. A new, detailed field mapping of the Po Valley side of the Northern Apennines carried out in the last ten years within the Emilia Romagna Geological Mapping Program has shown the presence of a large extensional fault crossing the high Bologna-Modena-Reggio Emilia provinces, from the Sillaro to the Val Secchia valleys. This Sillaro-Val Secchia Normal Fault (SVSNF) is NW-SE trending, NE dipping and about 80 km long. The age, based on the younger displaced deposits, is post-Miocene. The SVSNF is a primary regional structure separating the Tuscan foredeep units from the Ligurian Units in the south-east sector of the Northern Apennines, and it is responsible for the exhumation of the Tuscan foredeep units along the Apennine water divide. The subvertical, SW-NE trending faults, formerly interpreted as strike slip, are transfer faults associated to the extensional structure. A geological cross-section across the SVSNF testifies a former thickness reduction and lamination of the Ligurian Units, as documented in the field, in the innermost areas of the Bologna-Modena-Reggio Emilia hills, implying the occurrence of a former extensional fault. These data indicate that the NE side of the water divide has already gone under extension reducing the compressional domain to the Po Valley foothills and plain. They can also help in interpreting the complex Apennines kinematics.

T52B-0932 1330h POSTER

A Comparison of Structural Data and Seismic Images For Low-Angle Normal Faults in the Northern Apennines (Central Italy): Constraints on Geometry and Activity

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During the last 20 Myr extensional tectonics in the Northern Apennines have moved from the Tyrrhenian sea toward east. Much of the extension is due to low-angle east-dipping normal faults now exhumed in the Tyrrhenian islands and Tuscany, while still accommodating deformation in the Apenninic chain (Umbria region 200 km eastward). This tectonic framework provide an example where exhumed structures can be compared with active extensional structures and processes affecting the Umbria region. It is here proposed the case study of two of these low angle normal faults, the Zuccale fault (Zf), cropping out in the Elba island and the Altotiberina fault (ATF) mainly detected by seismic profiles crossing the Umbria region. The Zf in the eastern part of the Elba island juxtaposes along a gently (∼ 10°) eastward dipping contact, the Upper Cretaceous Helminthoid flysch in its hangingwall over the Permian-Triassic (?) phyllitic basement in its footwall. Structural analysis of the brittle structures that characterise the fault zone has been used to constraint the state of stress under which the fault slipped. From the N-S trending vertical vein system perpendicular to the slickenlines of the fault plane and from the Andersonian normal faults present within the fault gouge, some of them rotated according to a top to the east movement, we infer that (1) the maximum principal stress was sub vertical during the fault activity (2) the fault accommodate slip under low values of differential stress and at dips similar to its present flat geometry (3) local fluid overpressures were attained during the fault activity favoured by a thick fault gouge. The geological scenario described in the Elba island shows similarities with the active deformation of the Umbria region. Seismic profiles crossing this area matched with surface geology highlight the presence of an east-dipping low-angle (∼ 20°) normal fault, the Altotiberina fault (ATF), and antithetic seismogenic structures bounding the intramountain basins (Upper Pliocene-Quaternary). The

ATF itself is characterised by microseismicity and inversion of both focal mechanisms and geological data of the region define an extensional stress field with vertical σ_1: the fault therefore has been moving at high angles ($\sim 70^{\circ}$) from the maximum principal stress. Local short lived attainment of tensile fluid overpressure ($P_f > \sigma_3$) on small portions of the ATF and mainly due to the strong mantle degassing which affect the region, is proposed as explanation for the microseismic activity.

T52B-0933 1330h POSTER

Structural Transition from Extensional to Contractional Deformation in the Campania-Lucania Apennines and Apulian Foreland, Southern Italy

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A deep crustal seismic reflection line traversing the central Southern Apennines and Apulian foreland in southern Italy together with our mapping and compilation of surface data can be interpreted in two end-member restorable sections. The restorable sections differ primarily in the treatment of poorly imaged structures underlying the Bradano foredeep along the western margin of exposed Mesozoic carbonate rocks of the Apulian foreland. One section invokes extension to accommodate differential elevations of seismic reflection markers below the Bradano basin and is the more conventional interpretation of the two. In the extensional interpretation, orogen-parallel faults downdrop the foreland to the west toward the extinct frontal part of the Apenninic contractional belt. In this interpretation the foreland carbonate rocks exposed along the Adriatic coast are clearly decoupled from the contractional orogen and are not involved in Apenninic deformation. In the alternative interpretation, contractional faults and folds are invoked to explain the seismic marker offsets beneath the Bradano basin. In this interpretation the seismic markers are uplifted on west-vergent thrust faults that migrated spatially from east to west through time. In the frontal parts of the Apenninic orogen, the younger west-vergent faults cut older east-vergent structures and are responsible, at least in part, for the development of thick-skinned structures within the medial zone of the Southern Apennines. Active faults in the medial zone of the Southern Apennines are extensional and transcurrent but near offshore seismicity on faults of the Adriatic Sea and near Gargano are contractional and transcurrent. The combination of earthquake focal mechanisms and GPS velocities derived from the Peri-Tyrrhenian Geodetic Array support the contractional interpretation for structures beneath the Bradano foredeep and Apulian foreland. The preferred restored section provides a structural framework linking coeval contractional and extensional structures in the Southern Apennines and Apulian foreland.

T52B-0934 1330h POSTER

Active Extension and Contraction in the Southern Apennines Orogenic Belt, Italy Derived from GPS Velocities of the Peri-Tyrrhenian Geodetic Array

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A velocity field determined for 13 GPS sites of the Peri-Tyrrhenian Geodetic Array located in the Southern Apennines, the Apulian foreland, and the Calabrian arc of southern Italy is consistent with simultaneous extension and contraction within the orogen. GPS sites located in bedrock were occupied in 1995, 1997, and 2000 for 18 to 24 hours during each campaign. The GPS data were processed using BERNESE (4.2) in the IRTF97 realization using continuous GPS sites at Matera in southern Italy, Noto in southern Sicily, and Cagliari in Sardinia for reference. In a reference frame fixed on Matera in the southern Apulian foreland, sites along the Tyrrhenian coast are consistent with active seismicity and reflect crustal extension. The sites along the Tyrrhenian-margin are moving SW at 2-6 mm/yr, with the highest rates along the coast and decreasing easterly in the Apenninic highlands. Within the medial zone of the Apennines, located along the physiographic interface between the carbonate highlands of the Apennines and the subdued topography of the deformed synorogenic rocks of the foreland, localized convergence (6 mm/yr) and divergence (8-9 mm/yr) occur along a NNW-SSE axis. In the south, two sites move NNE at 3-4 mm/yr and converge on a site farther north moving SSE at 3 mm/yr. The northern-most site lies north of a NE trending fault system and diverges from the central medial zone with a NNW velocity of 6 mm/yr. GPS sites in the Apulian foreland northeast of Matera are moving west. Velocities decrease from south to north from 7 to 4 to 1 mm/yr from the Murge platform to Gargano. GPS velocities and seismicity indicate that the Apulian foreland is decoupled from the basement and actively deforming as part of a system of structures underlying the Adriatic Sea. Differential motion between the Apulian foreland and the medial zone is consistent with right-transpression. Simultaneous shortening and extension within the medial zone may be associated with arcuation of the frontal thrust belt. Orogen normal extension along the Tyrrhenian margin is probably related to crustal delamination and formation of seafloor in the Tyrrhenian Sea.

T52B-0935 1330h POSTER

The Brittle/Ductile Transition Along the Crop03 Seismic Profile (Northern Apennines): Relationship with the Geological Features

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The Deep Seismic Reflection Profile, Crop03, extending across the Northern Apennines (NA), from the Tyrrhenian to the Adriatic coastline has provided a good definition of the geological structures within the NA a NE verging thrust and fold belt. The accretionary process started in the Tertiary and is still taking place along the Apennine front. Starting in Early Miocene, extensional tectonics cross-cut the compressive structures and migrated toward the Adriatic Sea. The integration of information obtained with the Crop03 profile together with information coming from other geophysical soundings has allowed to picture in more details two adjacent structural domains, the Tyrrhenian (Western sector) and the Adriatic (Eastern sector), that make up the NA. These two domains have peculiar characters both from the geological and the geophysical point of view and the transition between the two domains occurs in a belt passing through the Perugia-Lago Trasimeno area. In this area the Crop03 project has shown a clear image of a regional east-dipping, low-angle, normal fault (Alto Tiberina fault) that crops out west of the Tiber Valley and dips towards NE, beneath the Apennine Chain, to a depth of about 12 km. This fault plays a key role in the development of regional seismicity but its geodynamic meaning in relation with compressional tectonics that has involved the Apennine Mountain Belt, is still unclear.

The aim of this work is to verify the correspondence between the brittle/ductile (B/D) transition and the geological and geophysical characters of the formations crossed by the seismic profile. In order to reach this aim a 2D numerical simulation will be used to obtain the deep thermal regime. The temperature field has been obtained verifying the choice of the physical parameters assigned to the rock units through the constraints offered by the Curie's isotherm and the lithosphere-asthenosphere transition. The obtained distribution of the temperature shows that under the western sector, at depth deeper than 30 km, the temperature exceeds $\sim$1600 K. This means that this region is characterized by a considerable amount of partial melting underlining that the high values of the surface heat flow observed in this area are also due to an asthenospheric contribution. The behavior of the B/D transition depth allows to subdivide the NAin at least three different sectors:-a Western sector, from the coast line of the Tyrrhenian to the Val di Chiana basin, in which the B/D transition is up to 10-12 km;-a Central sector, from the Val di Chiana basin to approximately the front of compression, in which the B/D transition dips abruptly towards the east from 12 km to 24-28 km in depth;-an Eastern sector, from Montiego to the Adriatic coast, in which the rheological behavior of the lithosphere is more complex: in fact it is brittle from surface to a depth of about 24-28 km and from 34 km downward. In between 24 and 34 km the behavior is ductile. The obtained trend of the B/D depth points out the presence of a peculiar zone in correspondence with the seismic image of the Alto Tiberina fault. Here, the peculiarity of the B/D (going abruptly from a depth of about 10-12 km, that characterizes the western sector, to a depth of about 30 km of the eastern sector) suggests that this sector of the NArepresents a transitional area between the western extensional sector and the eastern compressional sector of the orogen. This could explain the observed low surface heat flow and the not yet completed crustal thinning even in presence of an extensional active tectonics.

T52B-0936 1330h POSTER

Lithosphere-Asthenosphere Structure and Active Tectonics in Central Italy

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We investigate the lithosphere-asthenosphere structure and the active tectonics along a stripe from the Tyrrhenian to the Adriatic coast with emphasis on the Umbria-Marche area by means of surface-wave tomography, and inversion studies for structure and seismic moment tensor retrieval. The data include seismic waveforms, a large compilation of local group velocities (0.8-4s) and regional phase and group velocity (10-100s) measurements. The local group velocity maps cover the area reactivated by the 1997 Umbria-Marche earthquake sequence. These maps suggest an intimate relation between the lateral variations and distribution of the active fault systems and related sedimentary basins. Such relation is confirmed by the non-linear inversion of the local dispersion curves which provides the thickness and the characteristic S-wave velocity of each tectono-stratigraphic unit evidenced in the CROP03 profile. To image the deeper structure from the Tyrrhenian to the Adriatic coast, we fix the uppermost part of the crust using the Umbria-Marche models along with the CROP03 profile and related shear wave velocity, and invert the additional long period dispersion measurements. The results of the inversion show the geometry and lateral heterogeneity of the lithosphere-asthenosphere system.

The retrieved models for the Umbria-Marche upper crust reveal the importance of the inherited compressional tectonics on the ongoing extensional deformation and related seismic activity. The in-depth structural changes in the upper crust are likely controlling fault segmentation and seismogenesis. The reactivated 1997 normal fault zone displays a typical thrust fault geometry as evidenced by the lateral extent of the faulted Late Triassic evaporites layer that did not yet balance the cumulative normal faulting deformation attesting therefore recent extensional tectonics within the thrust belt. Our data are in favor of a listric geometry of faulting at depth. Source inversion studies of the two main crustal events of September 26 and October 14, 1997 show the dominance of normal faulting mechanisms, whereas selected aftershocks between the reactivated fault segments reveal that the prevailing deformation at the step-over is of strike-slip faulting type. The rupture of the three distinct and neighbouring fault segments seems to be controlled by a combined effect of transverse structures with strike-slip faulting mechanisms and of a change in the geometry of faulting.

At the scale of the Central Apennines our study provides a sound evidence of a lithospheric slab beneath the Apenninic chain, reaching at least a depth of 150 km, along with a set of velocity models that map the lateral extent of the crust-mantle boundary and lithosphere-asthenosphere system from the Tyrrhenian to the Adriatic coast. Between the subducting and the overriding plates, we report a lithospheric transitional area that reaches a depth of more than 100 km that could probably be a relic of the earlier east dipping Alpine subduction. This body is probably decoupling at depth the adriatic lithosphere undergoing compression from the Tuscan extensional domain. At shallow depth, we report a doubling of the crust-mantle discontinuity that we interpret as a result of an earlier sinking of the Adriatic plate where one part of the crust being detached from its sedimentary cover interfered with the laminated transition crust-mantle boundary of the overriding plate.

T52B-0937 1330h POSTER

Relief and Drainage Integration as Geomorphic Expressions of Regional Uplift and Local Footwall Flexure in a Portion of Sila Massif, Southern Apennines (Calabria, Italy)

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In active tectonic regions, topography is the result of the interactions of tectonics that deforms and moves rock masses and surface processes that rearrange materials on the resulting relief. First-order topographic features in a tectonically active landscape including relief, drainage patterns, and stream gradient slope represent ways to quantitatively characterize the interaction between tectonics and geomorphology, providing a basis for modelling landscape evolution. The Sila massif (Calabria, Italy) is a good place to characterize tectonic rates and processes through geomorphic investigations. Here the Apennines are a relatively narrow, articulated chain, composed of more or less uniform, crystalline pre-Alpine plutonic and metamorphic rocks, that appear to have been rapidly raised above sea level in the Pleistocene. Previous and ongoing studies contain information whereby the relative unroofing of the range and absolute uplift of rocks with respect to sea level can be reconstructed. Our study examines the tectonic geomorphology of the northern portion of the Sila massif focusing on the general topographic metrics, drainage patterns, and river longitudinal profiles. Our goal is to develop a general, but comprehensive picture of how the Calabrian Apennines are evolving tectonically in the context of the recent and rapid uplift (1 mm/yr) of the entire Italian Peninsula, taking in particular account the influence of extensional tectonics in the landscape evolution. Our main data base is composed of map and DEM-based topographic analyses, supplemented with field investigations of marine and fluvial terraces. These data are consistent with a landscape dominated by intra-chain extensional tectonics including block tilting and flexure of footwall uplifts, superimposed on a regional rock and surface uplift. The overall drainage pattern for the northern portion of Sila massif expresses a strong tectonic influence on stream integration dominated by the processes of integrating the largely interior drainage of the Sila massif, and adjustments to the ongoing uplift and subsidence of local extensional faults surrounding the plateau. Flexural uplift of the western and north-eastern edges of the Sila massif, a process we think might be driven by the isostatic response to footwall unloading, works to keep the edges of Sila high-standing. The uplifted edge prevents the drainages from integrating and fully dissecting this landscape. As a result, the clear geomorphic expression of active normal faulting is well evident around Sila, but is masked within the massif itself allowing the general perception that it is a vertically uplifted plateau. Futhermore, the marine terrace data on the Ionian coast that suggest an uplift rate of 0.9 mm/yr in the last 220.000 years confirm the broad uplift of the area. These results support the notion of a old landscape less rugged than the modern one that is coincident with a slow uplift related to syn- and late-orogenic exumation, the eastward migration of the arc, and roll-back in the subducting slab. In the Pleistocene the wavelength of deformation broadened and was characterized by an increase of uplift rate. Our general model for the long-term landscape evolution of the Apennines through Calabria places some fundamental, base line limitations on geodynamic considerations of how topography is generated in this convergent plate margin setting.

T52B-0938 1330h POSTER

Quaternary Tectonic Evolution of the Area of the 1997 Colfiorito Earthquake, Italy: Comparison Between Surface and Subsurface Observations

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Following the 1997 Umbria-Marchean seismic sequence geodetic, GPS and SAR Inteferometry measurements were performed. The results of these analyses put in evidence the surface deformation pattern of Colfiorito area which was interested by the main seismic events. This area is represented by a system of Quaternary intramontane basins characterized by internal drainage, filled by fluvio-lacustrine sediments and bounded by NNW trending normal faults showing controversial evidence of recent activity. The study of the geologic and tectonic evolution of the area has been conducted through surface observations and indirect investigations whose results have been compared. A detailed field survey has allowed to characterize paleosurfaces and Quaternary landforms and rock formations to point out recent fault structures activities. Indirect methods such as resistivity and refraction seismic profiling and mechanical drillings show the existence of peculiar landforms in the bedrock surface underneath the Colfiorito plain. Localized depressions underneath the fluvio-lacustrine sediments are located in the north-western part of the plain. This is consistent with the coseismic deformation pattern from SAR Interferometry and GPS showing a relative subsidence maximum in the same area. Our results demonstrate that the tectonic deformation is expressed by wide areal deformations and not by surface ruptures along fault planes.

T52B-0939 1330h POSTER

Digital Elevation Model Analysis Highlighting Tectonic and Lithologic Control on Landscape Morphology in Bedrock Environments: an Example From The Central Appennines, Italy

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We performed a series of topographic analyses on a 20 m resolution Digital Elevation Model (DEM) of the Central Appenines, Italy, to determine the relative influence of tectonic rates and rock type variations on hillslope relief. Uplift rates between 0.3-0.8 mm/yr along high-angle normal fault structures in the orogen's interior form a system of Quaternary intramountain basins. A complex geologic history exposes rock types including limestones, dolomites, turbidite deposits, and volcanic rocks. We compared different relief parameters (slope, local relief, residual relief) to the rock units and proximity to active faults to asses the first-order controls on hillslope relief. We grouped topography by comparing summary statistics and histogram morphology of different lithologic units and proximity to active faults. From our groupings, we found that rock type is the primary control on the bedrock hillslope relief, whereas current tectonic uplift rates find little or no expression in this relief. We plotted points in selected basins according to their upslope contributing area vs. local slope to infer the differences in the distribution of topography (and perhaps geomorphic surface transport processes) in different rock types. We found that differences in relief between rock types may be explained by the changing importance of different geomorphic surface transport processes in each exposed rock type. Our results indicate: 1) relief parameters used to deduce tectonic slip rates in areas where different rock types are exposed may be unreliable, and 2) landscape development models that do not consider lithologic variations cannot properly characterize hillslope relief in a bedrock landscape with different exposed units.

T52B-0940 1330h POSTER

Seismicity and Deformation Pattern along Apennines Chain (Italy)

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Along the Apennines we find a continuous seismicity, mostly concentrated within the chain, generally of moderate magnitude but that sometimes reaches also great magnitude as the Irpinia, 1980 event (Mw=6.8). Focal mechanisms show that all along the chain extensional events are present, but in the northern part also compressional earthquakes occur. In the same region, subcrustal seismicity (as deep as 90 km) is also present. Deformation patterns in a tectonically active region can be studied using earthquake moment tensors. Harvard CMT (1977 to present) and regional CMT (1977 to 1997 occasionally, 1997 to present up-dated continously) are available to apply for this kind of study in the italian region. A simple summation of moment tensors performed on a regular grid show the deformation pattern distribution. In the Northern Apennines the compressional regime in the outer part of the chain move to an extensional regime within the chain. In the Southern Apennines the extensional deformation prevails. Also a three-dimensional distribution of deformation and stress pattern is shown, with a deeper location of compressive respect to shallower extensional events.

T52B-0941 1330h POSTER

The location of potential large earthquake sources in the Apennines: major constraints from minor seismicity

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Strong efforts have been made over the last several years in Italy to both identify the major sources for large earthquakes and locate events of even the smallest magnitude. As of today at INGV, two databases were compiled to accomplish these tasks: 1) the database of seismogenic sources for the largest earthquakes (M> 5.5) which includes 60 fully-parameterized seismogenic sources and 181 tectonic lineaments; and 2) the database of instrumental seismicity for the past 20 years which includes about 50000 accurately located earthquakes that allowed the selection of 285 seismic sequences. We use these two databases to search for possible associations between seismic sequences and known/supposed earthquake sources in the Apennines.of minor earthquakes could be grouped according to both horizontal distribution and depth, with 5 groups falling within areas of undergoing tectonic deformation with different styles: 1) the Tyrrhenian side (horizontal extension) is characterized by shallow seismicity (0-5 km) which clusters in a limited number of sequences; 2) the Inner Apennines (major normal faulting) are characterized by a significant number of well clustered sequences at depths of 5-15 km; 3) the Outer Apennines (mainly undetermined style of deformation) exhibit sparse seismicity and diffuse sequences at depths of 10-20 km; 4) the Adriatic side (horizontal compression) has few shallow (0-10 km) sequences; 5) areas affected by large tectonic lineaments (undetermined kinematics), which mark discontinuities in the lithosphere or in the crust, exhibit wide depth range seismicity (0-30 km). A significant number of seismic sequences, especially those of group 2, also show clear association with known seismogenic sources for they frequently occur at fault-segment boundaries and activate different fault segments at short time distance.in all, the analysis low-magnitude seismicity yields interesting inferences on the occurrence of future large earthquakes in the Apennines because 1) seismic sequences delineate fault segmentation, 2) large normal faults seem to be bounded by weak zones, and 3) weak zones may either correspond to areas with a different rheology or to clearly-detectable, pre-existing transverse structures.

T52B-0942 1330h POSTER

Regional and Local Variations of Present-day Stress in Italy

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We present an improved map of the active stress field in Italy (previous compilation was by Montone et alii, JGR, 1999) obtained from more than 450 horizontal stress directions derived from breakout data (30%), earthquake focal mechanisms (65%), and other data. Although relative to different depth intervals and to different structural units, the data generally show consistent stress directions within the main Italian tectonic provinces. As described in previous studies, an extensional regime affects most of the Apennines belt, whereas a compressional (or transpressional) regime

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characterizes the Alps, the eastern side of the northern Apennines, the area between the southern Tyrrhenian Sea and northern Sicily. A strong rotation in stress directions marks the transition between the northern and southern Apennines, suggesting that the two arcs are characterized by different tectonic setting and recent evolution. We use the present-day stress map for a better understanding of active tectonic processes and to foresee the behaviour of faults recognized with other methods. In this work we compare active faults inferred from independent data (historical and recent seismicity, geomorphic observations, paleoseismological data, etc.), with the map of active stress orientations. This comparison allows us to identify both the orientation of the regional stress field and local stress rotations resulting from specific geologic and tectonic features. We observe a first-order agreement of the stress regime and orientation with fault kinematics inferred from geological and seismological data, as in the extensional/compressive structure of the northern Apenninic arc and in the extensional belt of the Southern Apennines. Sudden stress rotations appear to mark the location of major segment boundaries, suggesting that these coincide with singularities of the geologic structure. This circumstance may be used in future studies to explore the state of segmentation and hence the seismic potential of poorly known areas where large earthquakes are expected.

T52B-0943 1330h POSTER

Structural, AMS and Paleomagnetic Data on Plio-Pleistocene Sedimentary Basins in Eastern Sicily: Deformative Pattern in a Back Arc, Foredeep to Foreland System.

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Structural, paleomagnetic and AMS data, collected in the Plio-Pleistocene sedimentary basins of Eastern Sicily, are presented.

In Eastern Sicily, over a short distance, different structural domains are exposed: the southern margin of back arc Tyrrhenian extensional basin in the north, the compressional Quaternary Catania foredeep basin, and the Hyblean foreland in the south, characterized by a complex geometry of normal faults.

Results give new constrains on the Quaternary tectonic evolution of eastern Sicily. AMS results are typical of weakly deformed sedimentary sequences, with a magnetic foliation, parallel to the bedding plane, and a well defined magnetic lineation, whose orientation is controlled by the main tectonic elements recognized in such basins. The magnetic lineation is always parallel to the extensional direction obtained by fault-slip and joint analyses. Structural and AMS data define a transition from NW-SE extension in the southern Tyrrhenian margin, to E-W compression in the foredeep domain, to E-W extension in the foreland domain of the eastern Hyblean Plateau. The latter is mainly controlled by Quaternary activity of the Malta escarpment.

Paleomagnetic results show that no significative vertical axis rotations occurred in either extensional, foredeep and foreland basins. The timing of the irrotational tectonic regime can be certainly constrained to the middle Pleistocene and, according to the result of one site from Trubi Formation, could be extended back to the lower Pliocene. These data allow, therefore, to define an upper limit to the huge vertical axis rotations measured in Sicily region.

T52B-0944 1330h POSTER

Lithosphere - Asthenosphere Structure Beneath Central - Southern Apennines (Italy) From Nonlinear P-Wave Tomography

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We present new results for the P-wave velocity structure beneath the Central-Southern part of the Italian peninsula, obtained by inverting an improved dataset and extending the usual linearized approach of traveltime tomography to non-linear tomography. The data used in the imaging are the relative arrival times of over 5000 P-phases, accurately handpicked from teleseismic waveforms recorded by the Italian seismic network in the last decade. Data from a temporary array of ten stations deployed in southern Italy in the frame of an ongoing passive experiment (Saptex) were also included to provide a more complete and homogeneous ray geometry. The tomographic model is computed by means of an iterative sequence of linearized inversions incorporating a 3-D minimum travel time ray-tracing. At each iteration, a weighted damped least square solution is determined by using the singular value decomposition (SVD) method to better test the spatial resolution of the reconstructed anomalies. Beneath central Apennines the tomograms reveal a continuous, SW-dipping high-velocity body, from $\sim$ 150 km down to $\sim$ 500 km. At shallower depths, a pronounced low-velocity zone is recognized from the uppermost mantle beneath the Apenninic belt down to $\sim$ 200 km below the Tyrrhenian area. This feature is proposed to affect the seismic structure of the downgoing slab, weakening its velocity signature. Beneath southern Apennines, high-velocity anomalies are reconstructed in the uppermost mantle of the Apulian foreland and below the belt between $\sim$ 100 and $\sim$ 400 km. Low-velocity regions, interpreted as due to asthenospheric upwelling, are recovered above or across the fast structures, as at the southeastern end of the Apennines where a possible complete slab breakoff is suggested.

T52B-0945 1330h POSTER

Seismic Anisotropy in the Italian Region from the Upper Lower Mantle Boundary to the Crust

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SKS splitting measurements reveal the pattern of a strong seismic anisotropy in the mantle below Italy, Pn inversion (Mele et al., JGR,1998) shows an anisotropic behavior of the upper most mantle and shear wave splitting analysis on seismic sequences at local distances enhances the presence of crustal anisotropy. The anisotropic structures at these three different levels show some consistency; in fact they are all related to the presence of the Apennines mountain belt.

The complex pattern of SKS fast directions is not easily interpretable but is certainly constrained by the presence of fragmented lithospheric slabs and of asthenospheric flows induced by slab retreat. Pn velocity is anisotropic especially along the major arcs (Northern Apennines and Calabrian arc) with a fast direction that follows the arc signatures. Crustal anisotropy is observed at two sites in Northern and Central Apennines and seems to be related to the local Apenninic structures. These observations suggest that the orogenetic process of the Apennines is a process that involved the whole upper mantle and lithosphere characterizing the deformation pattern of the area.

T52B-0946 1330h POSTER

Slab Attachment in the Northern Apennines

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In the last decade many efforts have been made to better understanding the geodynamical evolution of the Mediterranean region, considered in the general context of the interaction between the Eurasian and African macro-plates. In particular, the major source of new information on the nature of the lithospheric processes acting in the region during the last 20-30 million of years has been the application of tomographic techniques by different authors. A relevant part of the complex boundary between Eurasia and Africa is represented by the Apennines, and the upper mantle slab structure imaged by tomography beneath this mountain belt has been invoked as responsible for their arcuate, asymmetric structure.

In the early 90s the idea of slab detachment was proposed as possible explanation for the non-continuous seismic velocity structure imaged by tomography beneath the Apennines as well as below other regions of the Mediterranean. In particular, lateral migration of the slab detachment from north to south along the Italian peninsula has been proposed as the engine driving the upper mantle dynamics beneath the Apennines. This view influenced numerous studies explaining different geophysical and geological data in the framework of the detachment process. However, in the same years other tomographic models suggested a different slab structure beneath the Apennines. Here we present a critical review of tomographic and geodynamic models and try to reconcile the major present day observables with different settings of the subducted lithosphere.

T52B-0947 1330h POSTER

Receiver Functions Analysis across the Northen Apennines

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The syn-collisional extension of the Northern Apennines is well established mainly from tomographic images, active faulting and geological data. A step forward in understanding how this process began, and how is going on, is the modelling of dynamic processes causing syn-collision extension. This requires the knowledge of several, still lacking, geometric characteristics of the deep structure. Among these, crustal structure, depth and geometry of main discontinuities is priority for dynamic modelling. For this reason, we deployed 10 continuosly recording broad-band seismic stations from Corsica to the Adriatic coast for five months during the past millennium, with the aim to apply receiver function analysis, to gain refined tomographic images, and to explore anisotropic characteristics of the upper mantle. We recorded several tens of teleseismic events with magnitude larger than 5.0 (up to Mw=8.3) with a good azimuthal coverage. Receiver functions are performed for teleseisms in the epicentral distance interval between 30° and 100° through classical frequency-domain deconvolution. Following the approach developed by Di Bona (1998), we could provide a variance estimate for single receiver function, assessing the statistical accuracy of amplitudes. This procedure allows us to use small magnitude events (Mb=5.0) generally excluded from receiver function analyses. Results show that individual converted arrivals have a large consistency for each station. The best receiver functions will be inverted for fine crustal structure following the inversion scheme proposed by Sambridge (1998). Finally, the dataset has been provided to the Dept. Of Geology and Geophysics (Yale University) with the aim to compare independent estimate of receiver functions (see Levin et al., this session).

T52B-0948 1330h POSTER

Mapping the Structure of the Lithosphere-Asthenosphere System Under the Alpine Orogen with High-Resolution Teleseismic Tomography

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Understanding the evolution of the Alpine orogen and the interaction between different lithospheric blocks requires precise knowledge of the structure of the lithosphere-asthenosphere system. To assess the gross features of the uppermost mantel we perform high-resolution teleseismic tomography. The data base encompasses 5000 manually picked first P-arrivals from

220 teleseismic events with even azimuthal distribution recorded at permanent and temporary seismic networks in the greater Alpine area. The tomographic study consists of these components: (1) Corrections for the contribution of the Alpine crust to travel-times of incoming wave fields that may account for up to 50% of the observed travel-time residuals. The 3-D crustal model established from controlled-source seismology data represents the large-scale Alpine crustal structure which clearly reflects the effects of the African-European plate collision. (2) Tests with synthetic data document that the combination of non-linear inversions, high-quality teleseismic data, and usage of an a priori 3-D crustal model allows reliable resolution of cells at 50km*50km*30km with a velocity variation in the order of ± 3% in the upper mantle. (3) Our tomographic images illuminate the structure of the uppermost mantle to depth of 400 km reflecting the complex processes that formed the Alpine orogen when three different plates were amalgamated (European, Adriatic, and Ligurian plates). In the western Alps, the inversion results show a steep W-E dipping high-velocity anomaly which we interpret as the subducting European plate. In the eastern Alps we find high-velocity anomalies in a depth range of 150 km to 300 km beneath the axis of the orogen. At present, the relation of this material with European or Adriatic lithosphere remains unclear. Our results are in general agreement with earlier lithospheric studies. However, the increase in resolution illuminates significantly more complex lithospheric slab geometries, which vary along the axis of the orogen, than assumed in previous geologic models.

T52B-0949 1330h POSTER

Analytical Modeling and Space-Geodetic Observation of Post-Seismic Deformation After the 1997 Umbria-Marche (Central Italy) Earthquake

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In the fall of 1997 a moderate size ($M_w = 6$) and shallow earthquake struck Central Italy. According to recent deep seismic reflection studies, surface-wave tomography and depth distribution of the related aftershock sequence, the seismogenic layer in that region appears to be thin (8-9 km) and decoupled from the lower part of the crust. Within this particular setting, which includes the presence of a low-viscosity transition zone and lower crust, viscoelastic relaxation is expected to be a major term in governing postseismic deformation.

Viscoelastic deformation is quantified following a normal mode approach for a stratified, self-gravitating and viscoelastic Earth; particular care is taken in reaching the high-resolution required by the small scale of this event. We focus our attention on the two main shocks that occurred on September 26, 1997, and after obtaining a good agreement with the observed coseismic displacement, we study the viscoelastic relaxation expected in the first 10 years after the earthquake. For reasonable viscosity values in the transition zone and lower crust ranging between 10^{18} and $10^{19} Pa \cdot s$, relatively high deformation rates are expected to occur at the surface. Both vertical and horizontal rates between 1 and 5 $mm \cdot yr^{-1}$ are possible to occur in a region of a few tens of km around the epicentre, depending on the chosen viscosity values and observation times.

The modelled deformation pattern for the years 1998-2001 is compared with measurements obtained by means of space geodetic techniques, namely GPS and InSAR and also to the seismic strain pattern revealed by the aftershock sequence. GPS data, coming from a local network installed across the fault and occupied on a yearly basis since the fall of 1999, are analysed by means of two different techniques: a multibase mode using the software package Bernese and Precise Point Positioning with ambiguity fixing using GIPSY. For the SAR Interferometric measurements of the area, we considered a set of interferograms covering different time spans within the years 1998-2000. Merging the redundant information from these partially overlapping interferograms helps to reduce the effects of temporal decorrelation on the whole two-year period. Additionally, GPS data are integrated in the interferometric measurements in order to check phase unwarpping errors. We show that the layered viscoelastic structure of the crust and mantle imposes a pattern and scale on the modelled coseismic and postseismic deformations with a major contribution from the transition crustal zone and low-viscosity lower crust, stress relaxation in the mantle being negligeable. We analyse the relation between the deformation fields averaged over different temporal and spatial scales and discuss the mechanical behavior of moderate-magnitude earthquake faults.

T52C MC: Hall D Friday 1330h

Continental Rifting and Passive Margin Development: Rift to Drift
(joint with S, V)

Presiding: **N Morewood,** Univ College Dublin

T52C-0950 1330h POSTER

Crustal Structure and Continental Margin Development Within the Svalbard Caledonide Terrain Based on Modeling of Ocean Bottom Seismometer Data

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The Barents Sea is located in the northwestern corner of the Eurasian continent, where the crystalline basement was assembled in the Caledonian orogeny during the Silurian period. Multichannel reflection seismic lines mostly do not resolve the structure well below the Permian sequence, and the post-orogenic development is not well known. Four ocean bottom seismometer (OBS) profiles that were collected in 1998 south of Svalbard is presented here. One profile was shot across the continental margin, and two profiles were shot as tie-lines on the continental shelf, together with one short profile to the north not crossing the others. P-wave modeling of the OBS profiles supports the presence of a Caledonian suture as previously proposed from interpretation of a deep seismic reflection line coincident with one OBS profile. The suture is associated with a small crustal root and westward dipping mantle reflectors. It also forms a boundary between two different crystalline basement terrains; the western part with low (6.2-6.45 km/s) P-wave velocities, the eastern part with higher (6.3-6.9 km/s) velocities. Gravity modeling supports a change in crustal terrain, as a higher density is needed in the eastern block. The results of the modeling of the S-wave data were not so clear on this, but very variable results indicate a strongly heterogeneous basement terrain. Immediately east of the suture zone there is a 15 km deep, early post-Caledonian sedimentary basin, restricted to the west and north. These observations can be explained by a model assuming westward dipping Caledonian subduction and collision, followed by post-orogenic extensional collapse mainly to the southeast. Subduction erosion may explain the missing lower crust in the western block. The outer 30 km of the continental margin is dominated by two large rotated fault blocks with throws of 2-3 km each, apparently formed during the Tertiary transform margin development and opening of the Norwegian-Greenland Sea. Due to the very low tectonic thinning of the continent at the margin, the continent-ocean boundary can be located to within 5 km. On the oceanic side, a top basement velocity of 6.55 km/s shows a missing oceanic layer 2, though the high (7 km/s) velocity reported earlier from expanding spread profiles is not observed.

T52C-0951 1330h POSTER

Tectonic Evolution of the Svalbard Continental Margin - Results from Seismic Refraction Experiments -

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In 1997 and 1999 the western and northern continental margins of Svalbard were geophysically explored by a German/Polish/Japanese scientific team. Main target of the surveys was the determination of the crustal seismic velocity structure. Therefore four seismic refraction profiles, with a total length of 1300 km were carried out across the continental margin. On the northernmost profile across the southern Yermak Plateau stretched continental crust is present up to 81 N. Seismic velocities vary between 5.1-6.9 km/s, therefore we exclude a rifted-volcanic evolution for the southern part, as supposed for the origin of the entire Yermak Plateau. The E-W striking profiles from Knipovich Ridge across the western continental margin of Svalbard show local zones with slightly elevated seismic velocities up to 7.2 km/s in various depths within continent-ocean transition zone (COT). The structure of the adjacent continental crust is similar to that on Yermak Plateau. Thinned oceanic crust with a thickness of 2-4 km is oberserved westwards of the COT. The deeper structure within the COT shows strong variations along the western margin. A 180 km broad COT is found at 79.8 N (northern Svalbard). Approximately 100 km further to the south at 79.0 N (Kongsfjord) the COT narrows to 40 km followed by the abrupt termination of continental crust to the adjacent oceanic crust. We interprete this part of the margin as a sheared continental margin. Off Van Mijenfjord at 77.8 N the width of the COT broadens again to 80 km and forms a normal stretched non-sheared part of the margin, as observed in the north. It seems that the Spitsbergen Fracture Zone of the complex Fram-Strait MOR-system was active while to the north and south normal stretching of continental crust occurred. The occurence of bodies of higher seismic velocity between 77.8 N and 79.8 N might be explained by the close distance of the newly developing margin to active spreading center segments. A limited amount of mantle derived melts was injected into the COT.

T52C-0952 1330h POSTER

RAPIDS 3: Imaging Beneath the Southern Rockall Trough Using Wide-Angle Seismics

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The Rockall And Porcupine Irish Deep Seismic (RAPIDS 3) project, funded by the Petroleum Infrastructure Programme, Rockall Studies Group, involved the acquisition of four wide-angle reflection/refraction seismic profiles in the Irish sector of the Rockall Trough. 2-D travel-time modelling has been completed and indicates typically a 4 – 5 km thick sedimentary succession within the central part of the basin thinning to c. 1 km on the surrounding basement highs. Significant topography modelled on the crystalline basement most likely represents a series of rotational fault blocks. Three main seismic packages have been identified within the sedimentary succession which is thought to be of Late Palaeozoic to Recent age. A 3-layer crust of c. 30 km thickness is modelled beneath the Porcupine and Rockall Highs thinning to 6 – 8 km beneath the basin with maximum thinning occurring beneath the edges of the basin. The three intra-crustal layers also thin and merge together such that beneath the centre of the basin a 1 or in some places a 2-layer crust is observed. Sub Moho velocities are lower than would be expected beneath the centre of the basin suggesting that some form of alteration of the upper mantle may have occurred.

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