cidence of deep (h > 300kms) seismicity. The SE Siberia-N China region, adjacent to the subduction beneath Sikhot Alin, is subject to unobstructed westward flow towards central Asia, and is the site of continental "back-arc spreading", extension and effusive vulcanism. In the south, the subduction-axis is distant from the mainland, and westward flow tending to restore equilibrium is impeded by the Tibet/Nan Shan geoidal high, a product of the Indo-Asia collision. This has resulted in the formation of the Szechwan basin, west-bounded by surface features such as the Lun Men Shan overthrusting. Thus we hypothesize that the tectonic flow seeking to restore equilibrium is in part effected by westward near-surface (lithosphere) motion from the Pacific towards central Asia. The relation between the geopotential and tectonic features seems to permit the existence on only a limited scale of east-west extension of the Indo-Asia collision region (tectonics of escape).

T52C-5 1430H

Structural Variation Across a Trench-Trench Junction, Western Solomon Sea

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Using multi-channel seismic reflection data collected in the fall of 1987, we have imaged significant structural variations across a trench-trench junction in the western Solomon Sea. This is the site of a westward propagating continent/island-arc collision of the south-facing New Britain arc and the Australian continent (bounded by the north-facing Trobriand subduction system). Observed structural variations along the New Britain thrust front include an increase in thrust slice thickness west of the point of initial collision. Thrusts east of the collision shoal into a shallow decollement, those west of the collision are more steeply dipping and branch from a decollement which steps down section. We saw no deformation associated with Trobriand subduction west of the point of initial collision.

We relate these structural changes to at least four factors: irregularities in the subducting lower plate, overriding of the Trobriand wedge by the New Britain accretionary complex, a westward increase in sediment thickness starting just east of the point of collision, and erosion of the thrust front along channels of the Markham fan complex. The increase in sediment thickness is enhanced by partial constriction of the Markham Canyon by the Deboin Spur, a lower plate basement high located just west of the point of initial collision. Increasing sediment thickness is accompanied by thicker thrust sheets, which are in turn deformed by minor thrusts. The constriction of the Markham Canyon at the initial collision focuses erosion along the deformation front, resulting in a flat-topped morphology at the toe of the New Britain accretionary prism. Approximately 50 km west of the initial collision, the toe of the wedge is presently sliding as a relatively undeformed block along a decollement which intersects the sea floor at the deformation front. This block extends 15 km into the wedge, active thrust faulting occurs behind it.

T52C-6 1445H

A Finite Element Model of Large Scale Coulomb Deformation in Accretionary Prisms

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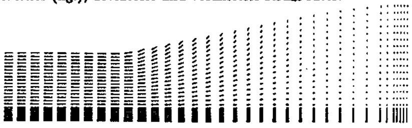
Critical Coulomb wedge models have been successful in explaining the large scale structure and geometry of accretionary wedges by explicitly assuming everywhere a static state of stress equal to the Coulomb yield stress. These models can be extended through the use of finite element techniques to consider the transient development of an accretionary prism and to consider the internal deformation implicit in these continuum models. To model the large strains involved in accretionary wedge deformation I use a velocity based, finite element formulation of plastic deformation. Model sediments are assumed to be compressible, but not deformable until the Coulomb yield criterion is reached, after which the material flows isotropically to remain at yield. The Eulerian formulation does not limit deformation either to infinitesimal strain or by excessive mesh deformation. It therefore allows large accretionary wedges to develop from originally flat-lying sediments. Deformation is driven by the opposing forces of the shear stress imposed by the subducting oceanic plate and a rigid continental "backstop". The model predicts the time dependent stresses, particle velocities (fig.), deviatoric and volumetric strain rates.



Velocity Relative to Upper Plate

Under drained conditions (the sediments are allowed to dewater with no change of fluid pressure) a distinct style of deformation develops. A wedge with a linear slope develops and grows in a self-similar fashion. The highest deviatoric strain rates are at the toe of the wedge where new sediments are accreted, but deformation is maintained at lower strain rates throughout the wedge to accommodate the self-similar growth. The largest volumetric strains are also near the toe of the wedge, suggesting that if the sediments have high permeability they will dewater quickly, near the frontal thrusts.

T52C-8 1515H

Rapid Long-Term Uplift and Denudation at a Collisional Plate Boundary, Eastern Taiwan

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The Coastal Range of eastern Taiwan, comprising an accreted island arc and overlying orogenic strata, has been uplifted rapidly to expose a thick sequence of Plio-Pleistocene marine deposits. Total uplift varies with local structure, reaching maxima at anticlinal crests where uplift rates average at least 6 mm/yr over the past 1.0 Ma. Long-term uplift of the Coastal Range is thus comparable to Holocene uplift rates reported for coastal areas of Taiwan (5 mm/yr over 9 Ka), measured by dating uplifted corals, although it is considerably surpassed by maximum local rates of current uplift determined geodetically. Long-term denudation in the Coastal Range has nearly kept pace with very rapid uplift, resulting in relatively low elevations (peaks of ~400 to ~1600 m). Long-term denudation rates for the Coastal Range are thus comparable to present-day denudation rates for the Central Range of Taiwan (≥5.5 mm/yr), calculated on the basis of modern sediment discharge; the higher elevations of the latter (up to 4 km) result from more resistant lithologies. These rates are also comparable to paleo-denudation rates for the ancestral Central Range during the Pliocene to earliest Pleistocene (4 to 5 mm/yr), inferred on the basis of geobarometric studies. Comparably high rates have been reported for short-term uplift in other convergence zones.

The recent, rapid uplift of the Coastal Range has been produced either by out-of-sequence thrusting or over a west-dipping decollement, in opposition to the west-vergence documented throughout most of the Taiwan mountain belt. The latter hypothesis is favored, despite eastward dips of most exposed thrust faults in the Coastal Range, because of the extreme eastward (hinterland) position of the Coastal Range on the east-facing topographic slope of the mountain belt.

T52C-9 1530H

Tectonic Deformations in the Eastern Mediterranean and Caucasia Due to Collision of the Arabian and Eurasian Plates

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The convergence of the Arabian and Eurasian plates produces extreme tectonic deformations in the eastern Mediterranean and surrounding regions. The tectonic deformations include the lateral (east-west) escape of the blocks bounded by the conjugate system of the strike-slip faults and the crustal thickening by thrusting and internal deformation. These tectonic deformations are studied by earthquake source mechanisms, field studies of active faults, and 2-D elastic finite element modeling. The calculations take into account both the transcurrent and convergent motions. Boundary displacements and the zones of maximum deformation (i.e., fault zones) are defined on the basis of relative plate motions and of the geologic data, respectively. The earthquake source mechanisms are used to determine the orientation of principal stresses and to constrain the models. Both field data and finite element models indicate that at plate boundaries (i.e., Arabia and Anatolia, and Anatolia and Eurasia), convergent type shortening dominates. In continent-continent sutures (i.e., Bitlis in Turkey and the Caucasus in the northeast) this is manifested as thrusting. In ocean-continent boundaries (i.e., Mediterranean and eastern Black Sea) the oceanic lithosphere is either subducting or being overthrusted by the continental crust. Between the two sutures, the predominant tectonic motions are due to escape of blocks to the east and to the west. These blocks are bounded by a conjugate set of transform faults. The largest earthquakes in the area occur on these strike-slip faults.

T52C-10 1545H

Balanced Cross Sections and Crustal Shortening in the Palmyride Fold Belt, Syria

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The Palmyride fold belt is a northeast-trending, 400 X 100 km transpressive belt in central Syria embedded in the northern Arabian platform, bounded to the north by the Aleppo plateau and to the south by the Rutba uplift. Palinspastically restored cross sections from three transects across the Palmyride fold belt demonstrate NW-SE shortening of at least 20% or 20 km across the southwestern segment of the belt, diminishing to 1-2 km in the northeast, close to the Euphrates graben system. The cross sections are based on previously unavailable seismic reflection and well data in conjunction with the 1:200,000 scale geologic map of Syria, all provided by the Syrian Petroleum Company. These results differ significantly from those predicted by kinematic models of Middle East plate motions.

In western Syria and eastern Lebanon the Palmyrides obliquely intersect (~45°) the roughly north-trending Dead Sea transform fault system. The Dead Sea system shows well-documented evidence of 105 km of left-lateral displacement since mid-Tertiary time south of its intersection with the Palmyrides, yet only about 25 km of motion is documented north of that juncture in Lebanon and western Syria. Thus, kinematic models of Middle East plate motions predict 80 km of shortening in Syria, most of which should be accommodated in the Palmyride fold belt. Several possibilities exist to explain the discrepancy between the 80 km of predicted shortening and the only 20 km of shortening measured from restored cross sections. (1) Restored cross sections offer only minimum shortening estimates, so the calculated 20 km may underestimate shortening. (2) Evidence of strike-slip displacement recognized in the field and in new focal mechanisms of two recent Palmyride earthquakes indicate that some of the still "missing" displacement may be distributed throughout central and northern Syria as strike-slip motion oblique to the relative northward convergence of the Arabian plate on the Eurasian plate. (3) Previous estimates of slip along the northern segment of the Dead Sea fault system may be too low. (4) The Dead Sea fault in western Syria may have been active for only the past 5-6 m.y. or so, i.e., it was either nonexistent or moved only slightly before the Pliocene. This final possibility would require that the northern and southern segments of the Dead Sea fault system developed independently during most of the past 15-20 m.y.

T52C-11 1600H

Uplift of the Nyainqentanghla and the Crustal Thickening History of Southern Tibet

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The Nyainqentanghla (NQTL) is a NE-SW trending mountain range of unusually prominent relief, approx. 125 km in length, located within southern Tibet about 100 km NW of Lhasa. It reaches elevations in excess of 7100 m and borders the western side of a large Quaternary graben whose floor is at or below 4600 m. Rocks exposed in the NQTL are dominantly peraluminous granitoids, granitoid gneisses, and pelitic schists. Previous work in the range indicates the crystallization ages of the metamorphic protoliths to be greater than 50 Ma; no data is available regarding the age of the (presumably younger) granites. While the granites in the NQTL may be similar in age to the granitoids in the Gangdese Batholith to the south (~100 to 40 Ma) they are distinctly different in composition and cooling history. Metamorphic assemblages indicate peak conditions of ~ 5 kbar and 600 °C. $^{40}Ar/^{39}Ar$ ages from biotite and K-feldspar from a granite in the southern part of the range (elev. 5510 m) indicate cooling > 50 °C/Ma at *ca.* 10-9 Ma. In the northern part of the range muscovites from two granites ~3 km apart at 4880 and 5020 m elevation yield essentially identical $^{40}Ar/^{39}Ar$ muscovite ages of 9.1 Ma; K-feldspars from these samples have minimum ages of ~6 Ma. Two float blocks of pelitic schist from this part of the range have concordant muscovite and biotite $^{40}Ar/^{39}Ar$ ages of ~8 Ma.

A thick (100's m) mylonitic high strain zone that displays normal fault shear sense indicators is exposed on the eastern margin of the central sector of the NQTL. This high strain zone is characterized by prominent ~15 ° E dip slopes and hogbacks on the eastern margin of the range which extend to elevations greater than 6500 m. It is cut out to the NE and SW by the younger steep normal faults that bound the present Yangbajian-Damxung graben. Two K-feldspar samples from gneisses within this high strain zone (elev. 4960 and 4800 m) yield $^{40}Ar/^{39}Ar$ age spectra with two plateaus at ~4 and 8 Ma. Biotite from one of these samples gives a $^{40}Ar/^{39}Ar$ age of 6.2 Ma. At a third location (elev. 4500 m) a leucocratic dike ~10 cm wide both cross-cuts and is deformed in this high strain zone. The K-feldspar $^{40}Ar/^{39}Ar$ age spectrum from this dike also exhibits two plateaus: at 4.3 and 5.6 Ma. Hornblende from an amphibolite adjacent to this dike gives a $^{40}Ar/^{39}Ar$ age of 6.5 ± 0.9 Ma. Age information combined with Arrhenius diagrams from the K-feldspars within the mylonite zone suggest that these samples were at temperatures between 400 and 300 °C from 8 to 5 Ma and subsequently experienced rapid cooling through 250 °C at 4 Ma. These data indicate the ductile fabric within this zone developed before 5 Ma.

Throughout the range, denudation rates over the last 12 to 10 Ma have averaged ~ 1 mm/year, perhaps punctuated by a more rapid pulse of uplift and denudation at *ca.* 8 Ma. We interpret the high strain zone to have formed during the early stages of extension of the present graben. This and other similar N-S grabens in southern Tibet have been interpreted to have developed after the Tibetan plateau reached its maximum sustainable crustal thickness and elevation. Our data therefore constrain the attainment of maximum crustal thickness in southern Tibet and the intiation of graben formation to be older than 4 Ma, and most likely between 8 and 5 Ma.

T52C-12 1615H

Mechanism of Deformation and the Nature of the Crust Underneath the Himalayan Foreland Fold-and-Thrust Belts in Pakistan

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Comparison of the Salt Range (SA) and the Sulaiman (SU) fold-and-thrust belts of the western edge of the Indian subcontinent, Pakistan, suggests a similar mechanism of deformation but underlying crust of different nature. These belts are similar in their gentle topographic slope (<1°), overall low dip of the top of the basement (<4°), great width compared to the rest of the Himalayas, and symmetrical structures. These similarities support a common deformation mechanism based on the bulldozer model. The main differences between these belts are best explained by different currently underlying crust. The SA is gravity over a few select seamounts. The lithosphere in the Superswell region of today has been shown to be thermally weakened over a broad area, producing seamounts with lower–than–normal elastic plate thicknesses. On the Darwin Rise, measures of subsidence on the guyots surveyed have provided evidence for a lithosphere that was also reheated around the time of volcanism and then subsided according to a normal depth–age curve. Results of modeling of gravity derived thus far show lower–than–normal elastic plate thicknesses, Te, in accordance with the subsidence data, and Te values also compare well with an earlier regional study conducted using satellite altimetric and dbdb5 data.

The analysis of gravity data over the Japanese, Wake, and Mid–Pacific guyots has been found to require precise bathymetric data. Although these guyots rise from a 4.5 to 6.0 km base to 1.5 km water depth, the small (5–40 km) summit radii and variety of complex shapes mean that simplified models of seamount bathymetry do not give reliable answers. By using Seabeam data collected on *Roundabout 10* as well as previously compiled SASS maps, profiles produced from 3–D synthetics can be compared to profiles of gravity with more consistent results. The RMS differences between real and synthetic lines gridded against elastic plate thickness and density parameters provide a good constraint to Te values and a moderate constraint to densities. Te values obtained over individual guyots by these methods have been in agreement with both suggestions in the gravity of a flexural arch and the earlier modeling from satellite data; we also see the effect of lower density in the reefal caps.

T52B-10 1600H

Subsidence Records from Pacific Atolls and Islands

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Seismic reflection profiles were examined from 360 crossings of the seamounts in the Hawaiian chain between Loihi Seamount (at the currently active end of the Hawaiian seamount chain) and Midway Island. Hundreds of drown reef terraces or wave-cut notches (with vertical and horizontal dimensions less than 75m), reef platforms (many kms in horizontal extent), and fault scarps have been identified. In most cases it is very difficult to differentiate between fault scarps and wave- cut terraces or drowned reef platforms. The highest frequency of occurrence of the terraces or notches is in the interval from sea level to 1500m. The larger platforms are commonly observed to depths of 3500m. It appears that faulting and mass wasting of the seamounts is an important control on formation of platforms on Hawaiian Seamounts.

Studies of similar acoustic profiles from seamounts in the Line Islands chain show a very different pattern of submarine features. In all but eight cases, the individual seamounts in the Line Islands chain are free of comparable terraces and platforms. Twelve islands, atolls, and reef banks reach sea level in that chain, and relatively flat tops are seen on the massive ridges in the northern and central Line Islands chain, but peripheral terraces and platforms are generally absent. Lithostratigraphic comparison of the rocks collected by dredging in the Line Islands indicates that the upper slopes of the Line Island seamounts are characterized by volcanic breccias. This substrate is less stable than the flow basalts that constitute the greater mass of Hawaiian seamounts. Thus, slope instability in the Line Islands seamounts appears to destroy much of the record of subsidence within the Line islands seamount chain.

T52B-11 1615H

Mass Wasting and its Influence on the Seismic Stratigraphy of the Hawaiian Flexural Moat

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The sediments filling the Hawaiian flexural moat should preserve a record of the lithosphere's flexural response to the load of the adjacent islands and their subsequent erosion and subsidence. GLORIA data recently acquired by the USGS in the Hawaiian area have demonstrated the importance of large-scale mass wasting in island erosion with slumps and debris avalanche deposits exposed over hundreds of km^2 of sea floor between Hawaii and Kauai (Moore et al., in press). We recently obtained over 4400 km of single channel seismic reflection data across the northern Hawaiian flexural moat that reveal a coherent moat stratigraphy consisting essentially of a series of stacked debris flows up to 2.6 km thick. Four major sequences can be identified. The uppermost sequence consists of relatively thin onlapping and ponded sediments restricted to the deepest part of the moat. Directly below this ponded unit lies an offlapping sequence composed of highly reflective horizons that dip inward toward the axis of the moat. This sequence is underlain by series of lense-like structures each composed of a chaotic core, bounded above and below by highly reflective, continuous horizons. This unit comprises the bulk of the sediments filling the moat and is thickest along the older part of the island chain between Oahu and Kauai where at least four separate chaotic lenses can be identified. The lowermost sequence consists of subhorizontal reflectors draping the underlying basement and probably pre-date the formation of the Hawaiian Islands.

Based on this stratigraphy, the sedimentary history of the moat can be reconstructed. Although the slope failures that produce these deposits begin early in the history of individual volcanoes, the volume of material supplied is initially not enough to keep up with the rapid subsidence of the moat due to flexural loading and the youngest parts of the moat are underfilled. At this stage sedimentation is dominated by along-moat transport of material from the erosion of older islands. Slope failures appear to culminate near the end of the sub-aerial shield-building stage of island construction forming the thick onlapping sequence of chaotic lenses and turbidites which fill the bulk of the moat. The largest debris avalanches (e.g. the Nuuanu-Wailau and Hana avalanches) segment the moat into a series of sub-basins and control the lateral transport of sediment along the moat. As the islands are eroded and subside, the influx of sediment to the moat decreases, the offlapping upper sequence forms and sedimentation is eventually restricted to the deepest part of the moat where the ponded sequence develops.

T52B-12 1630H

Robust Estimation of Regional Seafloor Depths in Seamount Provinces

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Estimates of the regional depth of the seafloor are of fundamental importance in plate tectonics. The subsidence due to cooling of the lithospheric thermal boundary layer explains the first order relationship between depth and age, and regional depth estimates are used to determine an empirical subsidence law for the cooling plate. Departures from this expected subsidence (depth anomalies) are thereby defined and may be interpreted in terms of epeirogenic motions and/or thermal rejuvenations caused by hotspot volcanism and/or mantle convective rolls.

We derive regional depth estimates directly from shipboard bathymetric measurements. These data have intrinsic errors which we evaluate by cross-over error (COE) analysis. COE analysis reveals systematic errors in some cruises which can be corrected. After correction, the median absolute COE in well-surveyed regions of the deep ocean is 25 m.

Estimation of regional depth is complicated by the presence of seamounts, which contribute bathymetric data shallower than the regional seafloor. Convolution procedures such as low-pass filtering or averaging of the depth measurements are biased by these shallow values and may not yield reliable estimates of regional seafloor depths in seamount provinces. We have developed "filtering" procedures which use robust estimation techniques including L1 norms to predict the value of the seafloor in the presence of contaminating "outliers" (the seamounts), and also to yield confidence limits on these estimated values. Regional depth and depth anomaly maps produced by our method agree with previously published maps where the seafloor is relatively uncomplicated; however, there are significant differences in many of the world's major seamount provinces. Our technique provides a direct separation of seamount and seafloor data populations and can therefore be used to estimate the volumes of volcanoes and other features which rise above the regional seafloor.

T52C CA:314 FRI 1330h

Compressional Tectonics II

Presiding: S D Willet, Dalhousie Univ; K Fujita, Michigan State Univ

T52C-1 1330H

Andean tectonics derived from a continuum model of the Nazca–South America subduction zone

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Numerical solutions of viscous flow models of subduction zones are used to investigate Andean tectonics. The tectonic activity of the Andes extends over a wide region, and is characterized by large scale extension and compression in close proximity: extension in the foreland, near the trench, and compression farther inland. The Andean tectonics is related to the subduction of the Nazca plate underneath South America, and indeed, the eastern limits of the tectonic activity coincides with the eastern limit of the Benioff zone seismicity. We use a plane strain viscous flow model of the uppermost 700 km of the earth to calculate numerically the velocity and strain rate fields within the overlying continental lithosphere. The rheology we choose is power law creep within the continental lithosphere, and linear flow in the asthenosphere.

Various calculations of subduction zone geometries, rheologies, and boundary conditions enable us to conclude the following:

- The subducting slab generates a small scale circulation of the asthenosphere between the slab and the overlying continental lithosphere. This suggests that simple corner flow calculations are valid at a finite distance from the wedge tip.
- Lithospheric deformation is concentrated between the trench and the surface projection of the tip of the slab, which is in agreement with the observations from the Andes.
- The calculated deformation of the overlying continental lithosphere shows a region of extension near the trench and compression farther inland, which is in accord with the Andean tectonics.
- The forces that govern the deformation are induced by the subducted slab near the trench and are balanced by shear tractions in the opposite direction, which are caused by the asthenospheric flow within the subduction zone.

T52C-2 1345H

On the Initiation of Subduction

S Mueller and R J Phillips (Department of Geological Sciences, SMU, Dallas, TX 75275)

Estimates of shear resistance associated with incipient lithospheric thrusting allow the establishment of lower bounds on the forces necessary to promote trench formation. Three environments previously proposed as preferential sites of incipient subduction are investigated: passive continental margins, transform faults/fracture zones, and extinct oceanic spreading centers. Our calculations suggest that none of these are likely to be transformed into subduction zones simply by the accumulation of regional gravitational stresses, since a force in excess of 10^{13} N/m is required. This may imply that subduction does not initiate through the direct foundering of dense oceanic lithosphere immediately adjacent to passive continental margins, even when extreme sediment loads and/or stress concentrations associated with compositional and elevational differences at ocean/continent boundaries are considered. Other potential driving forces are also considered and it is proposed that the forces responsible for the formation of new trenches invariably originate within existing trenches. This is consistent with a variety of studies indicating that along-trench variations in the magnitude of the slab pull force can induce compressional forces within non-subducted portions of the lithosphere which are comparable in magnitude to our minimum bounds. These compressional forces can be particularly significant when the arrival of buoyant material at the trench results in congestion. The common proximity of transform faults and fracture zones to subduction complexes suggests that if they are even marginally weaker than normal oceanic lithosphere they may represent the most likely sites of trench formation.

T52C-3 1400H

Collision Induced Ripoffs: Modern and Ancient

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Slab pull is thought to be a major force in determining the rate and direction of plate motions. Irregular or oblique convergence will result in closure of an ocean at some localities prior to others. Once a portion of the subducting plate has sutured, it will slow down or stop. Adjacent, unclosed sections, however, will continue to subduct under the influence of slab pull. This may result in tensional stresses in a portion of the subducting plate. As fractures are more likely to form in the weaker, continental part of the subducting plate, a fragment of the plate may be detached along an intracontinental rift system. Opening of this rift system would be limited to a small ocean basin since continuing subduction will close the remainder of the original ocean basin. This closure could then result in compression in the rift system. This sequence explains the near synchronous association of extension and compression, and the subsequent deformation of the rift fill, found in many once extensional regions.

The Red Sea is a modern example of this process. Closure of the Tethys occurred first in the Mediterranean and left a portion of the African plate, with attached oceanic crust, still subducting under the Zagros region. Continuing slab pull in this region, combined with the restraint to the west, induced the detachment of the Arabian Peninsula along the Red Sea and Gulf of Aden. Extension in the Proterozoic Mid Continent rift of North America was coincident with the Grenville compressional event to the south and east. The rift experienced only limited opening which we suggest was due to slab pull along an unclosed segment in the collision zone of the Grenville orogenic belt. Subsequently, the entire collision zone closed and the rift was pushed back into place, resulting in a complex pattern of folds, thrusts, and flower structures.

T52C-4 1415H

Dissipation of the W Pacific Geoidal High: Crustal Motion Towards Central Asia from Pacific Margin

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The geoidal high marking the W Pacific subduction belt is attributable to ongoing emplacement of dense lithosphere plate in the upper mantle. The process of "unpacking" and re-assimilation of the warming plate is attended by such phenomena as back-arc spreading, driven by the addition to the crust of material arising from the foundering slab. The process of assimilation takes place in an environment in which gravitation forces seek to re-establish equilibrium figure, dissipating the geoidal disturbance-field. The equilibrating forces are represented by the gradient in the geoid. In SE Asia (S China & SE Siberia), the geoidal gradient corresponds in several respects to large-scale tectonic provinces. The tectonics of the region is a function of the distance from the geoidal apex, marked by the in-

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