T 119

MECHANICS OF THIN-SKINNED FOLD AND THRUST BELTS

William M. Chapple (Dept. of Geological Sciences, Brown University, Providence, RI 02912)

Thin-skinned fold and thrust belts have a number of geologic features in common. 1) The original sedimentary section was wedge-shaped, thickening away from the craton. 2) The basement sloped backwards before deformation, does so now, and probably did so during deformation. 3) The whole wedge of sediments was shortened and thickened by the deformation. 4) Deformation occurs above a basal layer which was weaker than the rest of the wedge. Such a thin-skinned belt is modeled mathematically by the compressing flow of a perfectly-plastic wedge bounded below by a weaker layer. The solution derives the surface slope required to make the whole wedge yield and slide over the basal layer in terms of: yield stress of the wedge and of the weak layer, thickness of the wedge, and back slope of the basement. This surface slope can come from the observed thickening of the wedge. The commonly observed "inversion of relief" is a natural consequence of the shortening; no additional hypothesis is needed. If the basal layer is not much weaker than the rest of the wedge, a moderate forward slope of the surface is predicted. If the basal layer is very weak, or if its back slope is large (as might occur in a continent-arc collision), a flat or even a backward sloping surface is predicted. Stress orientation depends on the yield stress of the basal layer: if the layer is very weak structures will be symmetrical even near the base of the wedge, while if the layer is only moderately weak asymmetrical structures are predicted. This model explains both the shortening of the wedge and the basal shear stress; models which focus only on the surface slope can provide the basal shear stress but not the compression.

T 120

CATEGORIES OF ANOMALOUS TOPOGRAPHIC RELIEF WITHIN PLATES

S. E. DeLong
W. S. F. Kidd
K. Burke (all at: Dept. of Geological Sciences, State Univ. of New York at Albany, Albany, New York 12222)
Y. Isachsen (New York State Geological Survey, Albany, New York 12203)

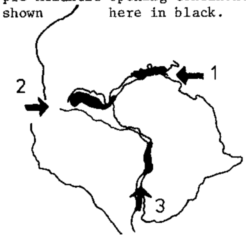
Most major relief on earth is associated with active plate margins. Continental and insular slopes separating the two platform areas defining the maxima on the first derivative of the hypsographic curve are the main regions of relief away from active plate margins. Problematic areas of major relief away from plate and continental margins fall into three main categories: 1.Some old mountain belts (e.g. Urals, Appalachians, and Caledonides). These elevations (1-2 km ASL) are too high to be relicts of orogenic topography and a problem is why are they high now. 2a.Active intraplate volcanic areas (hot spots) in both continents and oceans, are always associated with circular to elliptical structural uplifts of 1-2 km about 200 km across (e.g. Hawaii, Tibesti). Old hot-spot sites persist as seamounts in oceans, but are eroded in continents. 2b.Uplifts indentical to those associated with hot spots, but with no vulcanism (e.g. Adirondacks, Agulhas Plateau, Putorana and several in Southern Africa. The presence or absence of volcanic rocks in these two categories is probably of minor significance. 3.Other areas with 1-2 km of uplift, of linear to near circular plan, usually of major extent (≃1-2000 km). SriLanka and the Nilgiri Hills are protoplate margin relief associated with 6 my old aborted convergence. The Bermuda Rise, E. Brazil, Tornegat Mtns, Baffin Island, and the Eastern Rockies are each unique in certain aspects and are therefore difficult to classify. Areas of high relief in central Asia and China are a mix of plate margin, collision, and hot spot types.

T 121

ATLANTIC SALT DEPOSITS FORMED BY EVAPORATION OF WATER SPILT FROM THE PACIFIC, TETHYAN AND SOUTHERN OCEANS

Kevin Burke (Dept. Geological Sciences, State Univ. of New York at Albany, Albany, New York 12222)

Deep ocean basin exploration by research vessels of many countries has shown that salt diapirs have a restricted distribution around the margins of the Atlantic Ocean. Assuming massive salt was deposited only where diapirs have been mapped, areas of salt developed at opening may be plotted on a pre-Atlantic opening continental reconstruction as shown here in black.



Salt areas formed by spills from 1 Tethys (~170 m.y.)
2 - Pacific (~170 m.y.)
3 - Southern Ocean (~105 m.y.)

Inspection of this map leads to the new suggestion that three separate areas of salt exist each of which was formed by waters spilt from a different ocean. Tethyan waters spilt into the graben of Morocco and penetrated as far as what is now offshore maritime Canada in Late Triassic time. Flooding of the Gulf of Mexico by salt waters from the Pacific was roughly contemporary. This salt extended through a complex of graben around Florida to the Old Bahama Channel and the mouth of the Casamance river but not apparently farther north. In Aptian time salt was formed between the Walvis ridge and the Niger delta by a spill from the southern ocean.

T 122

HOLOCENE SEA LEVEL AND THE MARGINAL BULGE HYPOTHESIS

R.W. Fairbridge (Dept. of Geology, Columbia University, New York City 10027)

Daly (1920) proposed that loading of the earth's crust by continental glacier ice would produce not only a downwarp in the center, but also a marginal bulge. The amplitude of this bulge was tested by Newman, Fairbridge and Marsh (1969) and the flexure theory developed by Walcott (1972), confirming the concept of a bulge extending approximately 1000 km from the maximum limit of continental ice and reaching an amplitude of 50-100 m. Subsequent to the melting of the ice sheet there should be a fairly rapid recovery of crustal equilibrium, decreasing exponentially so that today very little residual remains. Tide gauge evidence of MSL behavior over the last 200 years suggests that the present recovery rate (i.e. subsidence) does not exceed 1-2 mm/yr.[1]

Records of Holocene shorelines from eastern North America tend to confirm the model but are confused by controversial interpretations. Accordingly a comparison has been made with five areally distinct Holocene shoreline curves for northern Europe, all based on modern, technically well-dated sequences by Geyh (1969), Mörner (1969), Ters (1973), Greensmith and Tucker (1973) and Tooley (1974). A 1975-updated version of the 1961 "Fairbridge Curve" based on "cleaned" equatorial to subtropical data suggests a crustal recovery in Europe comparable to that in North America. Anomalous amplitude departures in the English Channel and vicinity appear to be due to the changing tidal amplitude such as demonstrated for the Bay of Fundy (the Grant Effect). This work has been partially supported by ERDA.

as $1/\sqrt{t}$ and $\sqrt{t}$ respectively. At a sufficiently large age, however, the heat flow and depth depart from these simple relationships with respect to $\sqrt{t}$. The exact point at which this occurs depends on the value of κ/a^2, where κ is the thermal diffusivity and a the thickness of the plate. The empirical depth-age curve has been extended out to 160 million years using data at JOIDES drill sites and topography over identified Mesozoic anomalies. This confirms the behavior to be expected from a plate model, the departure from the linear relationship with respect to $\sqrt{t}$ occurring at 65-75 million years. The analysis allows the topographic and heat flow data to be characterized by a few parameters, each of which provides an exact relationship between the physical parameters of the lithosphere. In this way we can find a precise solution with error limits for T, the bottom boundary temperature, α ' the effective thermal expansion coefficient' and a. Furthermore, the parameters characterizing the data can be estimated in more than one way, providing a consistency check on the plate model.

T 105

RODRIGUES, DARWIN, ETC., A SECOND TYPE OF HOT SPOT ISLAND.

W.J.Morgan (Dept. Geology, Princeton University, Princeton, N.J. 08540)

Darwin (or Culpepper) and Wenman islands are about 200 km north of the main group of Galapagos islands and are aligned on a N 40 W trend. Rodrigues island is on a long E-W ridge about 900 km east of Reunion island. These trends are very different from fracture zone trends or hot spot trends in these areas. The Reykjanes ridge has been interpreted as due to Iceland "feeding" material down the axis; a sort of channeled asthenosphere plumbing from the hot spot (a "source of new asthenosphere) to active spreading rise (a "sink" of asthenosphere). We propose similar channeling for hot spots not exactly on a rise crest -- a "pipeline" from the hot spot to a nearby rise crest with this second type of island forming at the intersection of rise and pipeline. Possible tests of this hypothesis are proposed. Other islands which may have been generated by this mechanism are Amsterdam and St. Paul (Kerguelen), Balleny (Erebus), Flores (Azores), and Bouvet.

T 106 PRESENTATION BY TITLE

THE TIME RESPONSE OF THE SEA FLOOR AND PERIPHERIES TO A THERMAL RUNAWAY PULSE

A.R. Rice (Dept. of Geology, Columbia University, New York City 10027)

In addition to providing episodic transgression-regression cycles, periodic thermal runaway in mantle convection may lead to episodic wide-spread thermal stress failure of the oceanic crust.

Thermal expansion rents left in the sea floor by a heat surge from the mantle may later partially fill with basalts from below, sediments from above. The following thermal cooling contraction sequence would provide, in addition to a rachet effect aiding the thrust of plates under continental margins, sufficient compressive stresses to close the cracks, pushing the fill out on top of the ocean floor, to form aseismic ridges; ice shove is an analogous process. Regression, tectonism, island ridge volcanism would accelerate together with time as the elastic limit of the crust is gradually exceeded in different locales, with continued cooling preventing stress relief. Such a model requires aseismic ridges be located in the quiet magnetic zone with rather undisturbed sea floor elsewhere, and that the volcanics of island ridges follow progressively a tholeiitic to andesitic sequence. The model provides the stresses that appear necessary for deformation of basaltic materials.

The geologic time record provided by such a model should appear roughly as a "shark's fin" and "shark's tooth" regression and crustal activity curves. Evidence for this mechanism is discussed. This work has been partially supported by ERDA.

T 107

TEMPERATURES, RELIEF AND GRAVITY FOR A CONVECTING UPPER MANTLE

J.-Cl. De Bremaecker, Department of Geology, Rice University, Houston, Texas 77001

Convection computations are now very fast: a two-dimensional computation of temperature, streamlines, relief, gravity and heat flow in a convecting upper mantle of variable viscosity yields a pseudo-steady-state solution in about three minutes. This has made possible a systematic search for the best model. The following tentative conclusions have been reached: 1. Temperature in the upper mantle is within 10% of steady-state. 2. The general circulation is dominated by plate motions; the asthenospheric circulation may differ appreciably from steady-state, this is reflected in the gravity field over the oceans. 3. Gravity anomalies over the ridges agree with the models, those over the trenches do not: this confirms the presence of low density material. 4. The relief depends on the normal stress at top and bottom, the shear stress in the fluid and the temperature. The data are compatible with the models. 5. Paradoxically, Herring-Nabarro viscosity is a worse approximation than simple depth-dependent viscosity; thixotropy is incompatible with steady-state. 6. Qualitative agreement with the data is easy to obtain, but no single model has yet been found which satisfies them all quantitatively.

T 108

TEMPERATURE-DEPENDENT,NEWTONIAN AND NON-NEWTONIAN BOUNDARY LAYER FLOWS IN THE EARTH'S MANTLE

David A. Yuen
Gerald Schubert (both at: Dept. of Planetary and Space Science, University of California, Los Angeles, California 90024)

Narrow plume-like structures in the Earth's mantle are boundary layer flows, since both vertical velocity and temperature variations take place primarily in the direction transverse to the upward motion of the plume. It is of considerable importance to quantitatively determine how the thickness and the rate of growth of such a boundary layer depends on the rheological properties of the mantle. We have found an analytic similarity solution for the two-dimensional boundary layer adjacent to a vertical isothermal surface in a fluid with an arbitrary temperature-dependent, power law rheology of the form

$$\dot{\underline{\underline{\epsilon}}} = B(n,T)\left(\tfrac{1}{2}\,\underline{\underline{\tau}}:\underline{\underline{\tau}}\right)^{\frac{(n-1)}{2}}\underline{\underline{\tau}}$$

where $\dot{\underline{\underline{\epsilon}}}$ is the rate of strain tensor, $\underline{\underline{\tau}}$ is the shear stress tensor, T is the temperature, n is the index of the power law, and B(n,T) is an arbitrary function. Boundary layer structures are computed for temperature differences of 1000°C, 700°C, 400°C, for n=1 and n=3, and for rheological parameters characteristic of olivine. Very thin temperature and velocity boundary layers can be maintained over considerable vertical distances. The thickness and growth of the boundary layers are determined mainly by the activation energy and activation volume of the deformation process and to a lesser extent by whether the flow is Newtonian or non-Newtonian.

T 109

TEXTURAL AND MICROSTRUCTURAL SYSTEMATICS IN OLIVINE AND QUARTZ

C. Goetze (Dept. of Earth & Planetary Sciences, Massachusetts Inst. of Technology, Cambridge, Massachusetts 02139)

The dislocation density (ρ) in experimentally deformed single crystals of olivine is found to approach a steady value in the first 0.1-1% of strain, which is presumably controlled by elastic interactions between neighboring dislocations. This density correlates strongly with stress according to the relation $\sigma_1-\sigma_3=(9 \times 10^{-5}\text{kb cm})\rho^{1/2}$ for olivine and $\sigma_1-\sigma_3=(6.3 \times 10^{-5}\text{kb cm})\rho^{1/2}$ for quartz. By using the dislocation density as an indicator of the stress at which natural tectonites have been deformed, we have quantitatively compared naturally and experimentally developed textures. The following conclusions have emerged: (1) The secondary grain size (g.s.) in both naturally and experimentally developed porphyroclastic textures is correlated with stress according to the relation $\sigma_1-\sigma_3=(0.11\text{ kb cm}^{1/2})(\text{g.s.})^{1/2}$ for both olivine and quartz. (2) The mean spacing of (100) tilt boundaries in regions of the crystal where [100] Burgers vectors dominate correlates with stress according to the relation $\sigma_1-\sigma_3=(1.7 \times 10^{-3})(\text{mean spacing})^{-1}$, as suggested by Raleigh and Kirby. Using decoration and TEM techniques we have studied the texture and dislocation microstructure of 24 natural olivine-rich rocks. According to these systematics, rocks typically classified as "highly deformed", with obvious variable extinctions, result from stresses of 1-3 kb, while coarse-grained mantle-derived lherzolites from Hawaii, Nunavak Island, Kilbourne Hole, and San Carlos, Arizona, are compatible with differential stresses of 50-200 bars.

T 110

DIAPIRIC FLOW IN THE UPPER MANTLE: EVIDENCE FROM AN OPHIOLITE AND FROM EXPERIMENTS

H. G. Avé Lallemant (Dept. of Geology, Rice University, Houston, Texas 77001)
F. R. Kunze (Dept. of Geology, Rice University, Houston, Texas 77001)

The Canyon Mountain Ophiolite in Oregon has internal structures that resemble those of salt diapirs closely. The first deformation (F_1) caused isoclinal folds with vertical axes (b_1), very distinct lineations (l_1) parallel to b_1, and axial-plane foliations (S_1). The second deformation (F_2) is expressed by broad open folds, also with vertical axes (b_2). The fabrics of olivine (OL), orthopyroxene (OPX), clinopyroxene (CPX), and plagioclase (PL) in the tectonite peridotites, pyroxenites, and gabbros are almost ortho rhombic: maxima of Z-OL, Z-OPX, Z-CPX, and [100]-PL are parallel to $b_1=l_1$; weak maxima of X-OL, Y-OPX, Y-CPX and of poles to (001)-PL are normal to S_1. Results of extrusion tests on dunite at temperatures of 1100°-1200°C, pressures of 10-15 kb, and strain rates of 10^{-5}-10^{-7} sec^{-1} are consistent with a diapiric flow model for the Canyon Mountain Ophiolite. Strong Z-OL maxima formed parallel to the extrusion direction σ_3 (the minor principal compressive stress axis), and X-OL maxima developed parallel to σ_1 (the major principal compressive stress axis). The textures resemble natural dunite textures closely. The mechanism of flow is syntectonic recrystallization.

PLATE TECTONICS: ITS RIGOROUS GEOLOGIC BASIS II

(Cosponsored by O, S)
Sheraton South Room
Thursday 1330h

JOHN V. ROSS (Dept. Geology, Univ. British Columbia, Vancouver, B.C., Canada V6k1C3)
KEVIN BURKE (Dept. Geological Sciences, Suny, Albany, N.Y. 12222), Cochairmen

T 111

NON-NEWTONIAN THERMAL CONVECTION IN THE MANTLE

E.M. Parmentier (Dept. of Geological Sciences, Cornell University, Ithaca, New York 14853)

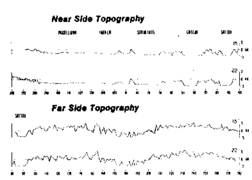
Studies of non-Newtonian thermal convection between horizontal boundaries have been carried out

Published monthly by the American Geophysical Union from 1909 K Street, N.W., Washington, D.C. 20006. Editorial and Advertising Offices: 1909 K Street, N.W., Washington, D.C. 20006. Subscription rate: $15.00 for calendar year 1975; this issue $5.00. Second class postage paid at Washington, D.C. and at additional mailing offices.

Claims for missing numbers, sent to AGU, will be honored only if received within 60 days after normal delivery date. No claims will be allowed because of failure to supply AGU with a change of address or because copy is 'missing from files.'

EOS

TRANSACTIONS
AMERICAN GEOPHYSICAL UNION
VOL. 56, NO. 6, JUNE 1975



Cover Topographic elevations on the Moon measured by the Apollo 15 laser altimeter. See William M. Kaula's article (from which this figure was taken) on the gravity and shape of the moon, and the Eighth GEOP Research Conference report, 'Lunar dynamics and Selenodesy.'

E⊕S is devoted to the publication of contributions dealing with the interface of all aspects of geophysics with society, and of semitechnical reviews of currently exciting areas of geophysics. Through E⊕S earth scientists should enjoy keeping abreast of new activity and be better prepared to face their own work with a broad perspective. This journal is an effective way to address or redress those who are involved in the study of the earth and its environment in space.