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"Strain Buildup and Release, Earthquake Prediction and

Selection of VLB Sites for the Margins of the North Pacific"

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Summary

Projects studying different aspects of crustal deformation in several areas are in progress or near completion. Evidence that the earth's crust is broken into blocks with dimensions of ten's of kilometers in orogenic belts was presented in a paper recently appearing in Tectonophysics. Results of a detailed study of the rifting process at the plate boundary in northern Iceland using combined seismic, tilt, and displacement measurements, were reported at the Washington, D.C. meeting of the American Geophysical Union. Stresses acting on the Alpine fault, New Zealand, were modeled based on observations of regional variation in metamorphism and argon loss. A paper detailing the results has been accepted for publication in the Journal of Geophysical Research. A study of the relation between the stress pattern shown by intraplate seismicity and possible stresses on plates arising from lithospheric motion over the asthenosphere is nearing completion. Recently begun projects include a study of smaller earthquakes located by the Southern California Seismic Array to determine if subregions of uniform strain release exist and to study the interaction of faults in the Los Angeles Basin and installation of two strainmeters of a new type near the San Andreas in Southern California on the edge of the Palmdale bulge to help monitor crustal deformation there. Also, two geologists from Columbia University are presently in the field studying the area around the Quincy Laser Ranging Site for evidence of any possible recent movement on nearby faulting which could influence the SAFE distances measurement.

Discussion

Understanding whether active block structures occur in a given area where strainmeters or tiltmeters are to be installed singly or in arrays is important since some of the elastic properties of the resulting surface fragmentation can cause interpretive ambiguity in observed data. In general, observed strain fields will be incoherent across block boundaries compared to strains within integral blocks. Strain magnitude can be reduced significantly within blocks which also may exhibit large tilts. The azimuth of observed principal strain axes may differ from the azimuth of applied strain axes in places where local strain fields are generated at block boundaries. Applied strain will normally be intensified at block boundaries if they are represented by relatively weak fault zones. Evidence for continental crustal block structures revealed by geodetic work during the last century is presented in a paper, "Strains and tilts on crustal blocks" by R. G. Bilham and R. J. Beavan which recently appeared in Tectonophysics. Blocks with dimensions ranging from 5 to 50 km appear to be common in regions of intense tectonic activity. There is some indication that block boundaries may respond viscoelastically or exhibit strain-dependent elastic properties. Such behavior can account for the slow transmission of tectonic deformation reported in Japan and elsewhere. If nonlinear behavior is a characteristic of regions fragmented by crustal blocks, it introduces problems for the interpretation of observed surface strain and tilt. In particular, it will not be possible to apply a site correction factor based on the observed distortion of seismic or tidal strains to the interpretation of secular strains.

Growth of large-scale ground fissures during rifting of the plate boundary in northern Iceland was observed using several geophysical techniques. The study area is the Krafla volcano and the cross-cutting fissure swarm that extends 70 km to the north and 30 km south. Displacement sensors installed across fissures measured continuous opening of fissures in the floor of the Krafla caldera. Episodic opening and closure of fissures outside the caldera was found during the magma migration event in September 1977. The currently ongoing tectonic activity in northern Iceland began in December 1975 with seismic activity, a minor eruption, land subsidence, and fissure motion. Evidence from S-wave shadows and gravity and leveling surveys indicates the existence of a magma chamber at a depth of 3 to 7 km below the Krafla caldera. Leveling surveys show variable tilting interpreted as inflation episodes due to filling of the magma chamber and deflation episodes related to migration of magma away from the chamber into the fissure swarm. Two migrations to the south and nine to the north have been observed. Fissures in the caldera open during inflation episodes and close during subsidence, as expected. A small left-lateral shear is observed in each subsidence episode. Also, a significant secular opening of the fissure accumulates with each cycle. Fissure growth in the rift zone is episodic. Virtually no fissure movement was observed prior to or after the September migration event. When fissures in the rift open, fissures outside the rift close. The implication of fissure closure is that the dike intrusion is to some extent forcibly wedging the two crustal blocks apart. Observations of compressive stress in the crust adjacent to the rift zone in Iceland, an extensional area in plate tectonic concepts, could be related to doming of the caldera and forcible dike intrusion. A paper detailing these observations is in preparation.

The Alpine fault of New Zealand is a major continental transform fault which has been uplifted on its southeast side 4 to 11 km within the last 5 m.y. This uplift has exposed the Alpine schists, which have been metamorphosed from the adjacent Torlesse graywackes. The Alpine schists increase in metamorphic grade from prehnite-pumpellyite facies 9-12 km from the fault through the chlorite and biotite zones of the greenschist facies to the garnet-oligoclase zone of amphibolite facies within 4 km of the fault. These metamorphic zone boundaries are subparallel to the fault for 350 km along the strike. The K-Ar and Rb-Sr ages of the schists increase with distance from the fault: from 4 m.y. within 3 km of the fault to approximately 120 m.y. 20 km from the fault. Field relations show that the source of heat that produced the argon depletion aureole was the fault itself. Adopting a friction model for the fault, and applying the known geological history of motion of the Alpine fault, we show that the metamorphic culmination resulted from frictional heating during the 360 km right-lateral slip on the Alpine fault during the Mesozoic (Rangitata) period of fault motion (140-80 m.y. ago). Fault motion began again in the Plio-Pleistocene Kaikoura orogeny, with 120 km of further right-lateral slip and 4-11 km of uplift. Frictional heating during this episode produce the argon depletion. Quantitative models for both the metamorphism and argon depletion require that the frictional shear stress acting on the fault during both episodes of fault motion was at least 1-1.5 kbar. If, alternatively, it is assumed that all fault motion took place in the last 30 m.y., this does not change our conclusion with respect to the stress required for the argon depletion.

The epicenter distribution of intraplate earthquakes in North America, to a first approximation, forms a ring of seismicity around the continent. Most of the seismicity is concentrated in the mobile belts which rim the interior platform and shield provinces. In contrast, the Precambrian shield and interior platform provinces are virtually aseismic. Evidence from seismology and heat flow indicates that ancient shield areas are characterized by thicker lithosphere and a deeper, less developed or even absent low-velocity zone when compared to oceans or continental areas of younger age. The "deep crustal roots" beneath shield areas may influence the basal drag as continental plates move laterally over the asthenosphere. If the bottom of the asthenospheric layer has a constant depth, then the reduction in asthenospheric thickness under shields will result in enhanced drag under these areas. In light of this hypothesis, the ring of seismicity encompassing North America may well reflect stress concentrations due to variations in lithospheric thickness and associated increased asthenospheric drag.

A two-dimensional finite element model of a continent moving over the asthenosphere was constructed and the resulting stress pattern was calculated. Stresses are enhanced at the shield boundaries. The stress pattern is antisymmetric from the front to the back of the continent and is either compressive or tensile at the leading edge, depending on whether the asthenospheric flow tends to drive the continent or resist its motion. Deviatoric stresses in the center of the continent are relatively low.

Phanerozoic mobile belts may represent pre-existing zones of weakness along which earthquakes preferentially will occur if a regional stress field is present. Also, the lithosphere tends to thicken at the continentward boundary of mobile belts where they contact stable platform regions, thus deviatoric stresses from basal drag will tend to concentrate in circling mobile belts, too. The two effects may work together to create the ring pattern of seismicity around North America. Two effects also may be responsible for the aseismicity of the North American craton. Because of their age, these areas may be "annealed" presently and act as strong blocks resistant to faulting. Secondly, the deviatoric stresses caused by basal drag beneath the continent will be minimal above the thickened lithosphere.

Study of instantaneous plate motions suggests that, within observational error, 'hot-spots' may be considered a fixed reference frame with respect to the translation of lithospheric plates. From observation of the Yellowstone and Raton hotspot traces, the North American continent appears to be moving in a westerly direction at a rate of about 2 to 3 cm per year. If resistive drag at the base of the lithosphere beneath continents is significant, a change from horizontal tensile to horizontal compressive deviatoric stress would be expected from west to east on a traverse of the continent. Indeed, such a flip in the stress orientation is suggested by focal mechanism and hydrofracture measurements. In view of the simple plate-tectonic model proposed, the regional stress patterns are consistent with basal shear being a resisting drag force that is concentrated beneath continental areas.

The northern boundary of Canada is approximately parallel to the absolute plate velocity vector, hence, the two-dimensional model presented may not be applicable in this region. The seismicity of northern Canada generally is located along the continental margin and available focal mechanisms do not appear to suggest the presence of an ambient horizontal stress field. If a regional stress field does exist, it may be radically influenced by local loading effects of sedimentation on the continental shelf. A paper detailing the model and data indicating stress orientations is nearing completion.

Development and installation of a new type of strainmeter were partially supported by the grant. An attempt was made in 1969 to use carbon fibers as a length standard in wire-type strainmeters. It was not successful due to the inherently high creep rate of the fibers when used as a 20,000 fiber composite wire. The reason for the poor stability was that the polyacronitrile charring process gave rise to graphite crystallite coherence lengths of about 10 meters. In any given 10 m long strainmeter more than half of the crystallites forming the wire would be discontinuous, adversely affecting the composite strength and creep properties of the bundle. Presently carbon fibers can be made from pitch and coherent lengths are virtually infinite. We have found that good stability can be obtained a month after installation (10^{-7} strain/month) for a 10,000 fiber bundle 40 meters long under a tension of 1.5 kg (15 Newtons). At present the fiber is clamped between thin lead washers, cemented with quick-setting epoxy, and drawn slightly until set. Ideally the clamping process evenly distributes the effective stress across the entire bundle of fibers but it is probable that the stress is mainly carried by a relatively small fraction of the 10,000 filaments. The tensioning device employed in the new strainmeter uses a 25 cm long lever that holds the fiber bundle under about 10 Newtons tension. The device is a balance that rotates if strain occurs in the ground. Rotation is detected by a symmetrical capacitance transducer. The useful sensitivity of the system is about 10^{-10} strain, above which ambient ground noise becomes significant. Three of the new strainmeters are presently in operation; one in Ogdensburg Seismic Observatory in New Jersey and two recently installed in California near the San Andreas fault on the edge of the Palmdale bulge.

A study of seismicity in southern California was recently begun. Locations and first-motion data from small to moderate size earthquakes recorded by the Southern Califonria Seismic Array were obtained and are being used to systematically determine focal mechanisms over a broad region of southern California including the Mojave desert, Transverse Ranges, and Los Angeles basin. The substantial expansion of the number of instruments operating in the area since 1975 allows location and focal mechanism determination for most events down to magnitude two. The smaller events are more numerous and more widely distributed spatially than larger ones previously studied, so a high resolution study of variations in regional tectonic deformation is possible. The study was begun with the ideas of seeing if seismic deformation indicated subregions of uniform stress distribution, how these regions relate to the different observable geologic regions, and how faults in the different regions interact at their boundaries. Data from 1975 through 1978 were obtained. Approximately 30 to 40 useful events per years are anticipated, so on the order of 150 focal mechanisms will be obtained. Initial interpretation and correction of the raw data have been performed but final results are not available. Preliminary results indicate that sharply bounded regions with considerably difference strain release patterns do exist in Southern California.

Recent studies of the geology of the Sierra Nevada Mountains, partially motivated by proposed construction of the Auburn Dam near Sacramento, California, indicate that older fault zones in the area thought to be inactive, instead have been the site of recent tectonic movement. Seismic and geologic evidence suggests that a graben-type structure is forming presently along a line from Lake Tahoe to Lake Almanor. The structures appear to be similar to those of the Basin and Range province located to the east and may represent an encroachment of the active tectonic regime there into the more stable Sierra block. Although no recent motion is known on faults near the Quincy Laser Ranging Site, two geologists from Columbia University are restudying the Quincy area to confirm this in light of present knowledge of fault reactivation in other parts of the Sierra. Their findings will be submitted as a supplemental report.

Publications

Bilham, R. G., and R. J. Beavan, 1979, Strains and tilts on crustal blocks, Tectonophysics, 52, 121-138.

Accepted for Publication

Scholz, C. H., J. Beavan, and T. C. Hanks, 1979, Frictional metamorphism, argon depletion, and tectonic stress on the Alpine fault, New Zealand, J. Geophys. Res.