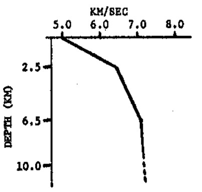

These results indicate that high-velocity, dense material is present at the near-surface and continues with depth, in agreement with the observed positive Bouguer anomaly. The velocities are typical of oceanic crust; however, no oceanic velocities are observed. The high-velocity material continues to the west of the cordillera but not to the east in the Cauca Valley. The tectonic origin of this range is discussed.

S 51

THE CHANGE FROM UNDERTHRUST TO OVERTHRUST TECTONICS ALONG THE PACIFIC-CAROLINE PLATE BOUNDARY

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Available seismologic and marine geophysical data indicate that a separate Caroline plate currently interacts with the major Pacific, Philippine and Indian plates and minor plates around the margins of the Caroline Sea. We suggest that the triple junction between the Caroline, Pacific and Philippine plates is located at the intersection of the Sorol Trough and the Yap Trench. Of primary concern is the unusual variation in tectonic processes along the Pacific-Caroline plate boundary. The northern section of the boundary coincides with the Sorol Trough which is primarily a strike-slip feature with some extensional characteristics. The southeastern section of plate boundary occurs along the Mussau Trench where the Caroline plate underthrusts the Pacific plate. The section of plate boundary between the Sorol Trough and Mussau Trench is characterised by highly unusual deformational tectonics. Convergence between the Pacific and Caroline plates is apparently accomodated here by overthrusting of small slivers of seafloor towards the northeast. The intensity of deformation appears to increase southward towards the Mussau Trench. Our calculated instantaneous angular rotation vector for the Pacific-Caroline plates predicts that convergence rates should increase uniformly south along the overthrust and underthrust sections of plate boundary. The transition in tectonic style from overthrusting to underthrusting occurs between 3° and 4°N. Perhaps here certain threshold conditions (determined by convergence rate?) are reached so that subduction is possible to the south along the Mussau Trench while overthrusting occurs along the section of plate boundary to the north.

S 52

THE MAKRAN REGION OF PAKISTAN AND IRAN: TRENCH-ARC SYSTEM WITH ACTIVE PLATE SUBDUCTION

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Geophysical and geologic data indicate the Makran region of Pakistan and Iran is an active subduction zone. Oceanic portions of the Arabian plate subduct towards Eurasia with rates of about 5 cm/yr. Most of the tectonic features of the Makran arc-trench system are somewhat anomalous. The anomalies include: The arc-trench gap measures 500 ± 100 km, twice the width of a typical arc-trench gap. The Benioff zone is only weakly developed to a depth of about 80 km with no reliably located seismicity at larger depths. Yet two focal mechanisms in the deepest documented part of the Benioff zone indicate down-dip tension in the descending slab. The 400 km long volcanic arc shows wide spacing (> 100 km) between its major volcanic centers. A large portion of the accretionary prism is subaerially exposed rather than submarine. The geologic record indicates that this active continental margin may have developed through most of the Cenozoic, and that large portions are still underlain by an oceanic infrastructure.

S 53

THE QUETTA-SIBI (PAKISTAN) SYNTAXIS: EVIDENCE FOR ITS ORIGIN FROM SEISMICITY AND PLATE TECTONICS

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Evidence from seismology and plate tectonics indicates that the Quetta-Sibi syntaxis may have developed as a result of right-lateral movement on a broad shear zone extending southeast from Quetta. Three large earthquakes have been associated with the Kachhi plain of Pakistan in the past 100 years. Intensity data for the two earlier events (1872, 1909) and aftershock data for the most recent one (1931) indicate that earthquakes in this area are caused by rupture of faults with a southeast orientation. A focal mechanism for an event in 1973, located within the inferred shear zone, is consistent with right-lateral movement along a fault plane parallel to those inferred for the large events. Such movement is compatible with the large-scale features of the Quetta-Sibi syntaxis observed today. Consideration of the current plate motions suggests the development of the syntaxis may be a natural consequence of the changing angle between the India-Eurasia plate boundary and the northerly direction of relative plate motion. In southern Pakistan plate motion is parallel to the plate boundary, but to the north the motion becomes more and more oblique. This oblique motion may decouple into thrusting combined with dextral shear (associated with crustal shortening) in the Quetta-Sibi syntaxial region and sinistral shear along the Chaman fault. Similar zones of convergence associated with oblique plate motion along the San Andreas fault in California and the Alpine fault in New Zealand were discussed by Scholz (1977).

S 54

POST-COLLISIONAL TECTONICS OF THE TURKISH-IRANIAN PLATEAU AND A COMPARISON WITH TIBET

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The Turkish-Iranian Plateau (Fig. 1) is a high region with an average elevation of about 1.5 km. During the late Miocene the last piece of oceanic lithosphere between the Eurasian and Arabian continents was eliminated at the Bitlis/Zagros suture zone. Continued convergence across the collision site resulted in the shortening of the plateau across strike by thickening and by sideways motion of parts of it. Predominantly calc-alkaline vulcanism is present on the highest portions of the area, despite the absence of a descending slab of lithosphere. Surface geology and vulcanism of the Turkish-Iranian Plateau resemble greatly those of the Tibetan Plateau, and both are underlain by a zone of seismic attenuation. From a comparison of these features and their tectonic setting we argue that the two plateaux are homologous structures, albeit at different stages of their evolution. Both areas appear to be tectonically alive and actively shortening. Available evidence lends little support to the hypotheses of large-scale underthrusting of continental lithosphere and of plastic-rigid indentation where such high plateaux, located directly in front of the "rigid indenter", are considered to be tectonically "dead". Their peculiar features are best explained in terms of shortening and thickening the continental crust whereby its lower levels are partially melted to give rise to calc-alkaline surface vulcanism. Minor associated alkaline vulcanism may be due to local longitudinal cracking of the crust to provide access to mantle.

S 55

SEISMOTECTONIC ASPECTS OF THE IRANIAN PLATEAU

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Travel time curves for P phases have been determined from regional and local earthquakes recorded at the Tehran Station and at the Iranian Long Period Array (ILPA). Travel time residuals have also been calculated and studied as a function of azimuth and distance. A structural model based on this newly obtained information is presented.

The focal mechanisms of the strong earthquake of November 1976 in northeastern Iran, and the March and April 1977 earthquakes in the Zagros region, were determined and the seismotectonic aspects are discussed.

S 56

A COMPARISON OF ZAGROS GEOLOGY TO ISLAND ARCS

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(Sponsor: Jack Oliver)

The tectonic models which have been previously suggested for the Zagros Mountain Ranges in Iran do not take into account the following geological and morphological aspects which are important for the orogenic history of the Zagros: (1) The Arabian Shield, which borders the Zagros region to the southwest, possesses a salient portion. This salient feature is contiguous to the Zagros Range in the Lurestan-Khuzestan region; (2) A nearly 600 km long depression is positioned between the Volcanic Belt and the Main Zagros Thrust; (3) The sediments in the Zagros become progressively younger from southeast to southwest; (4) The steep flanks of individual structures in the Zagros area are almost always on the southwest side; (5) The regional elevations increase from the southwest towards the Main Zagros Thrust. Considering these phenomena, the Zagros region is now interpreted as the result of collision and subduction, using present-day models. The Zagros displays an arc system in different stages of development. Although the arc elements in the southern Zagros (Fars area) and in the northwesternmost part (the region of the Rezaiyeh Depression) are well preserved, they are almost absent in a middle part which shows an advanced stage of collision. In this part, major flexuring and lateral movements are dominant.

S 57

RIDGE SUBDUCTION, EDUCTION, AND THE MECHANISM OF UPLIFT OF BLUESCHISTS

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Subduction of a spreading ridge beneath a continent, the ridge half-spreading rate being greater than the continent-ridge convergence rate, leads to the possibility of generation of new 'oceanic crust' beneath the continent and its emergence at the continental margin. This emergence, here termed *eduction*, provides a mechanism for exhumation of formerly subducted blueschists. An example is provided by the overriding of the East Pacific Rise south of the Mendocino transform by North America (~30 Ma). The relative motion between the Pacific and North American plates being in the direction of the future San Andreas fault, blueschists will be educted along those parts of the margin having a more northerly trend than the relative motion once the ridge is subducted. Also, as North America moves southwards over the Mendocino transform, blueschists, underplated on North America by the subducting Juan de Fuca plate, are carried south across the transform and educted by the emerging Pacific plate without being heated by the ridge. After coastal California joins the Pacific plate (inception of movement on San Andreas fault, ~7.5 Ma), eduction is restricted to that portion of the margin between the north end of the San Andreas system at Point Arena and the Mendocino transform (then both 450 km southeast relative to North America). As coastal California moves northwest it traps educted Franciscan rocks in the wedge-shaped gap between the northern part of the San Andreas fault and the former North American coast.

This model implies that the late Mesozoic K-Ar ages determined for the Franciscan do not reflect the time of uplift. We suggest that metamorphism at T<350°C may result in inadequate degassing of the protoliths and the consequent incorporation of large amounts of excess argon. There is good worldwide correlation between exposed blueschists and the sites of former ridge subduction.

refracted or reflected at a shallow interface, probably the base of the possibly permeable layer of pyroclastic material allows to trace variations in its depth. Amplitude anomalies on fan profiles for waves having travelled at 2 to 4km depth beneath an area of important surface manifestations-hot springs and fumaroles-may be attributed to the perturbation of the upper crust between the surface and the primary heat source or even to this region itself. For the delineation of geothermally interesting fields-superficial reservoirs or shallow heat sources-the use of these methods offers an alternative to seismic noise or microearthquake surveys which are severely limited by the adverse weather and sea-induced groundnoise level. Compared to models of the oceanic crust, the upper layers, with velocities smaller than 6km/s corresponding to oceanic layers 2A and 2B, are abnormally thick particularly under the central part of Sao Miguel where they reach a thickness of about 5km. Although the lower crust is also thicker than usual this accounts for most of the crustal thickening with respect to an oceanic model. Evidence of second arrival reflections indicate at least locally the existence of deep crustal interfaces. A 7.7 to 7.9km/s velocity derived for the uppermost mantle may be partially affected by uncontrolled variations in crustal thickness.

Lithosphere 6: Oceanic Crust, 2/ Continental Collision

Le Jardin (D), Wednesday 1330h

***A. K. Ibrahim* (University of Texas Marine Science Institute) and *K. H. Jacob* (Lamont-Doherty Geological Observatory), Presiding**

S 44

OCEAN BOTTOM SEISMOMETER STUDIES OF THE CRUST NEAR THE ORPHAN KNOLL AND FLEMISH CAP CONTINENTAL FRAGMENTS

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Seismic refraction studies have been carried out in Flemish Pass and the Orphan Knoll Basin, the areas separating the continental shelf northeast of Newfoundland from the Flemish Cap and Orphan Knoll continental remnants. Flemish Cap and Orphan Knoll are now separated from the nearest part of the shelf by distances of about 50 and 250 km respectively, and have often been shown as once lying against the continental shelf in plate tectonic reconstructions of the North Atlantic. The seismic refraction results give total depths to the M discontinuity of 19 km in the Orphan Knoll Basin and 23 km in Flemish Pass, indicating little difference in crustal thickness in the two areas. There is one main crustal layer with velocities in the range for normal continental crust, about 6.4 km/s, and several sedimentary layers above this. Upper mantle velocities of 8.0 and 8.2 km/s were observed. Several converted shear wave velocities were also measured, corresponding to the major crustal layers. These results confirm earlier interpretations of gravity and magnetic data which showed that these areas are underlain by anomalously thin continental crust. The relationship between crustal thickness and horizontal separation is such that the thinning of the crust appears to have taken place as a result of major subsidence and associated deep crustal and sub-crustal processes, rather than as a result of either necking of the crust or by sea floor spreading upon horizontal separation between the continental fragments and the adjacent shelf.

S 45

SEISMIC REFRACTION RESULTS FROM THE CONTINENTAL SHELF BETWEEN CAPE SIMPSON AND PRUDHOE BAY, ALASKA

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Nine refraction profiles study seismic velocities and crustal structure seaward of the crest of the Barrow Arch, an anticlinal structure which underlies the coastline from Camden Bay to Point Barrow. These profiles vary in length from 23 to 75 km and were completed from the USCG icebreaker BURTON ISLAND using a helicopter and sonobuoys. Seismic velocities lie between 2.0 and 3.4 km/sec for probable Tertiary and Cretaceous rocks. This sequence increases in thickness from 1.5 to 3.5 km towards the east. Velocities of 4.2 to 5.8 km/sec are associated with presumed early Mesozoic and late Paleozoic rocks. Those overlie pre-upper Devonian basement which has a velocity of 6.0 km/sec. Velocities of 6.8 km/sec are observed north of Smith Bay from a calculated depth of 4 km. Farther to the east, however, first-arrival velocities do not exceed 6.6 km/sec to distances of 75 km.

S 46

GAS SEEPS AND SUBSURFACE STRUCTURE IN THE NORTHERN GULF OF MEXICO OFF PANAMA CITY, FLORIDA

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Detection of rising gas bubbles in the water column above submarine gas seeps in the continental shelf and slope in the northern Gulf of Mexico, off Panama City, Florida has been made utilizing 3.5 kHz reflection records. Based on approximately 3800 km of reflection records in an area of 25000 sq km, six areas of gas seeps, one extending over 2400 sq km and the rest between 12 and 225 sq km, were recognized. Gas seeps are found to be restricted to the outer shelf, shelf break and uppermost slopes ranging in depth from 40 m to 250 m. Algal and shelly sand in the piston cores and irregular subbottom in the reflection records are indicative of reef growth in the seep areas. Total "wipe-outs" and "fuzziness" of reflectors and building up of mud mounds indicate the presence of gas within the sediments. While the aerobic conditions in the seep areas as indicated by its shelly fauna and infaunal bioturbation preclude the possibility that the gas is due to organic decay within the sediment, it is suggested that the porous sandy sediments have been effective in accumulating gas which moved upward from depth. Seven multichannel seismic profiles across the most extensive seep area show the presence of a dome which roughly coincides with the seep area in extent. The existence of a shear zone in the central part of the dome suggests a deepseated origin for the escaping gas. The dome is possibly a structural high with the peak shifting from one part of the dome to the other with time. This could be the result of stratigraphic buildup of reefs on a slowly rising dome. The occurrence of salt domes immediately southwest of this seep area is a noteworthy feature in this respect.

S 47

STRUCTURES OF THE WESTERN CONTINENTAL MARGIN OF BAJA CALIFORNIA

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Analysis of bathymetric, gravimetric, magnetic, and seismic data, obtained from recent marine surveys, yielded a series of geophysical maps and structural sections of Baja California. These maps and sections suggest the following: Franciscan-like basement rock extends from the Patton to the Coranado Escarpments. In continues toward the south, almost to the tip of the Baja Peninsula, gradually becoming more narrow. Its apparent continuity reduces the possibility of large horizontal displacements having occurred along major trans-peninsular faults. Linear, negative free-air gravity anomalies indicate a buried trench-like depression along the base of the Patton Escarpment, the possible shoaling of the mantle south of the San Clemente Basin, and that the 15 my old oceanic crust in the Cendros Trough west of central Baja is not yet in isostatic equilibrium. Progressively younger marine magnetic anomalies extend beneath the western margin of the peninsula indicating that either the East Pacific Rise axis migrated beneath the continent prior to the separation of the peninsula from the mainland or a northward component of motion of the Pacific Plate relative to N. America existed contemporary with rifting.

S 48

SEISMIC REFRACTION AND REFLECTION IN THE ARC-TRENCH GAP OFF GUATEMALA

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Seismic refraction and CDP reflection profiles were obtained during the summer of 1977 on the continental shelf and slope of Guatemala adjacent to the Middle America trench.

Six refraction profiles between 20 and 80 km length were recorded by Texas ocean bottom seismographs using airguns, maxipulse and explosive sources.

Travel-time curves based on first and later arrivals show velocities ranging between 2.0 km/sec and 8.1 km/sec. Some of the horizons identified by the refraction data are well defined on the multichannel section. Relatively high velocities (≃4.7 km/sec) are found at shallow depth in the midslope region and may indicate imbricate slices of layer 2 and indurated sediments within the slope. Landward dipping events seen on CDP profiles may be reflections from these slices. The top of oceanic crust with a velocity of 6.5 km/sec can be traced approximately 20 km landward from the trench axis. The mantle with a velocity of 8.1 km/sec is found to be at a depth of 13 km near the trench axis and can be traced landward for about 15 km.

S 49

SEISMIC REFRACTION OBSERVATIONS ACROSS THE CONTINENTAL LEADING EDGE IN SOUTHERN PERU

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Offshore-onshore seismic refraction observations were made in southern Peru in 1976. Two profiles examined the continental leading edge on either side of an inferred tear in the subducting oceanic lithosphere. Numerous 60, 600, and 1800# charges fired between the Peru-Chile trench and the coast were recorded at sites from the coast to the altiplano. Records of the northern profile show good reception of even 60# shots on the shelf at ranges in excess of 300 km, with signal-to-noise ratios uniformly higher than those from sites on the southern profile. The resulting record sections from these profiles exhibit gross similarities portraying the initial descent of the oceanic lithosphere with an apparent dip of 20-30 degrees. Structural models derived by ray tracing and gravity modelling are presented and implications of the difference in transmission characteristics for continental crustal structure are discussed.

S 50

SEISMIC REFRACTION RESULTS FROM THE WESTERN CORDILLERA, COLOMBIA

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The western cordillera of Colombia consists of metasedimentary and submarine basaltic rocks possibly of obduction origin. During Aug-Nov, 1976, seismic refraction measurements were made along and across this cordillera using Yumbo quarry as the source. Records were obtained up to a range of 200 km to the north and south, while a densely spaced profile was taken to 60 km to the west. Consideration of the observed travel-time curves, and their amplitudes, results in a velocity-depth function along strike with strong velocity gradients:

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Cover. The radar transmitter at the Arecibo Observatory in Puerto Rico is suspended approximately 200 m above the 300-m-diameter reflector. Together they form one of man's most powerful machines for the measurement of ionospheric properties, according to James C. G. Walker. See his article beginning on page 180.

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