03:30 p.m. Pan, Y. № 13119

STRUCTURAL AND THERMOCHRONOLOGICAL ANALYSIS OF A MAJOR LOW-ANGLE EXTENSIONAL SHEAR ZONE IN THE NYAINQENTANGLHA RANGE, SOUTHERN TIBET

PAN, Y., KIDD, W.S.F., Dept. of Geol. Sci., SUNY at Albany, Albany, NY 12222; COPELAND, P., Dept. of Geology, Univ. of Houston Central Campus, Houston, TX 77004; HARRISON, T.M., Dept. of Earth and Space Sci., UCLA, Los Angeles, CA 90024; RODEN, M., Dept. of Geology, RPI, Troy, NY 12180-3590

A major low angle shear zone several hundred meters thick in metamorphosed (amphibolite facies) Tertiary granitic rocks is found at the southeastern edge of the Nyainqentanglha range, in the southern Tibetan plateau. Foliations observed within the shear zone dip gently to the SE between 10-30°, toward the present Yangbajain graben. Various kinematic criteria at both field and microscope scale, including S and C foliations, consistently indicate a normal faulting shear sense. All the quartz and some feldspar grains show strongly developed features characteristic of solid state plastic deformation. This shear zone displays an asymmetric strain gradient with decreasing mylonitization down the section. The exposed top surface of the zone defines low-angle triangular facets prominent in the geomorphology of the eastern Nyaingentanglha. The quartz c-axis fabrics display high intersection angles to XZ plane, implying that prismatic slip systems were predominant during non-coaxial flow. $^{40}Ar/^{39}Ar$ and fission track data suggest rocks from and below this zone have experienced rapid cooling during the period ~10-3.2 Ma, with maximum cooling rate over 100 °C/Ma. Minerals from outcrops southeast of the high-strain zone did not register this young and rapid cooling. We suggest that this rapid cooling is related to fast upward motion and unroofing along the shear zone. As indicated by the ductile features and the quartz c-axis pattern, the temperature during most of the shearing deformation must have been over ~300-400 °C. Several biotites and muscovites (closure temperature around 330 °C-350 °C) yield $^{40}Ar/^{39}Ar$ ages of 6-8 Ma. This implies that the ductile shearing was occurring at that time. We interpret this shear zone to be a regional low angle ductile detachment, analogous to those associated with the metamorphic core complex structures described in the U.S. Basin and Range Province, and that it represents the early stage of extension in this region of Tibet.

03:45 p.m. Roden, Mary K. № 5706

EVOLUTION OF THE CONTINENTAL MARGIN OF WESTERN INDIA: NEW EVIDENCE FROM APATITE FISSION-TRACK DATING

KALASWAD, Sanjeev, Empire Soils Investigations, Inc., 105 Corona Ave., Groton, NY 13073 ; RODEN, Mary K., MILLER, Donald S., Department of Earth and Environmental Science, Rensselaer Polytechnic Institute, Troy, NY 12180-3590; MORISAWA, Marie, Department of Geological Sciences, State University of New York at Binghamton, Binghamton, NY 13902.

Apatite fission-track analysis of eleven samples of Archean/Early Proterozoic gneisses, schists and granites from the Western Dharwar craton, and one Late Proterozoic/Early Paleozoic sandstone from the Kaladagi Group in southwestern India yields ages ranging from 165 ± 21 Ma to 226 ± 19 Ma (Middle Jurassic to Middle Triassic). These apatite fission-track ages correlate with the breakup of Eastern Gondwanaland and Africa.

No significant response to the India-Madagascar split in the Early Cretaceous nor to the outpouring of the Deccan Trap basalts at the Cretaceous/Tertiary boundary is evident in the apatite fission-track ages determined in this study. This absence of thermal overprints due to Cretaceous rifting activity and/or basalt intrusions suggest that uplift and erosion of the region occurred prior to the Cretaceous and was related to Triassic/Jurassic rifting.

Confined track length measurements with mean track lengths of 12.0 ± 1.7 microns and 12.6 ± 1.6 microns point to slow uplift and cooling. Modelled time-temperature paths using the apatite fission-track age, track length distribution, and Laslett et al. (1987) equation suggest that slow cooling through 100°C began in the Late Paleozoic (~280 Ma) and became more rapid in the last ~60 Ma. This rapid more recent uplift is related to topographic doming of almost the entire west coast ot India during the Deccan Trap basalt activity.

04:00 p.m. Srimal, Neptune № 6575

ROLE OF PRE-COLLISIONAL EXTENSION IN HIMALAYAN OROGENY.

SRIMAL, Neptune, Geochronology & Isotope Geology Div., Geological Survey of India,15 Kyd Street, Calcutta 700 016, INDIA.

Some of the major problems in explaining Himalayan tectonics solely due to post-collisional deformation are:

Himalayan thrust planes, associated mylonitic foliation and regional foliation are parallel to the axial plane of the NE to NW plunging reclined (F_1) folds suggesting contemporaneity of these features. Major Himalayan metamorphism (M_1) is pre to syntectonic with respect to F_1. Thus, post collisional thrusting cannot be the cause of M_1. Since minerals related to M_1 define inverted metamorphic sequences any post thrusting model (e.g., hot iron model) for inverted metamorphism in the Himalaya is invalid. The F_1 fold axes which parallel the regional compression direction are suggestive of mega sheath folds. These mega sheath folds indicate high ductility in these rocks prior to F_1. Similarly, the difficulty of sustaining high heat flow in thrust thickened pile calls for a mechanism other than thrusting for widespread Himalayan anatectic plutonism.

I suggest the following model: rifting of continental slivers from the Himalayan margin of the Gondwanaland caused several periods of extension, the last of which continued throughout the Cretaceous. This Cretaceous extension caused crustal thinning and anomalously high heat flow in several parallel belts resulting in M_1. Deformation and stacking of this thinned, pre-heated and still hot crust of enhanced ductility after the India-Asia collision in the Tertiary caused widespread sheath folding, second metamorphism (M_2), overfolding of M_1 metamorphosed rocks resulting in inverted metamorphism, and later, in widespread anatectic plutonism. The present model of orogenesis explains many of the observed features of other orogenic belts in the world.

04:15 p.m. Burchfiel, B. C. № 32113

TECTONIC SETTING OF THE TIEN SHAN, XINJIANG, N.W. CHINA.

BURCHFIEL, B. C.*, DENG, Q.+, FENG, X.^, LI, J.^, MOLNAR, P.*, SHI, J.^, YOU, H.+ WU, Z.+,*Department of Earth Atmospheric and Planetary Sciences, Mass. Inst. Tech., Cambridge, MA., 02139; + State Seismological Bureau, Beijing, China; ^Seismological Bureau, Xinjiang, China.

The east-west trending Tien Shan of northwestern NW China rise to 5.600m and are flanked by the Tarim (south) and Jungar (north) basins (elevs. ~1.000m). They are composed of a collage of Paleozoic rocks dominated by arc volcanics overlain by Carboniferous molasse. Nonmarine Mesozoic-Cenozoic rocks are of variable thickness (1-10km). Conglomerate (clast size to 10cm) forms 5 to 20 % of the section. There is a dramatic increase in the amount of conglomerate in the poorly dated late Pliocene-early Quaternary rocks suggesting an increase in erosion due either to climatic change or to the onset of major deformation or some combination of both.

The present Tien Shan are a product of major late Cenozoic deformation related continued convergence between the Indian and Eurasian plates; they may account for about 20-40% of active convergence. Our studies of the folds and faults along the northern and southern margins of the range suggest the main topographic front of the range is dominated by fault propagation folds similar to the Laramide Colorado-Wyoming Rockies flanked by narrow belts of fold-thrust belt geometry detached within Mesozoic-Cenozoic rocks. This deformation is probably latest Pliocene - Quaternary. Fold-thrust belts migrated externally and are best developed along the SW and NE parts of Tien Shan and along the central and northern Turfan basin. Progressively older river terraces across active folds are more warped and offer the opportunity to determine the rate and partitioning of fold to fault deformation. Geometry of these structures indicates that major earthquakes, some to 45km depth, occur on faults beneath the high parts of the Tien Shan; flanking fold belts in Mesozoic-Cenozoic sedimentary rocks would probably not be the sites for great earthquakes (M=8.0).

04:30 p.m. Molnar, P. № 32112

ACTIVE FOLDING AND CONVERGENCE ON THE NORTH SIDE OF THE TIEN SHAN, XINJIANG, WESTERN CHINA

MOLNAR, P.*, BURCHFIEL, B. C.*, DENG, Q.+, FENG, X. ^, LI, J.^, SHI, J.^, YOU, H.+, WU, Z.+, * Department of Earth and Planetary Sciences, Mass. Inst. Tech., Cambridge, MA 02139; + State Seismological Bureau, Beijing, China; ^ Provincial Seismological Bureau, Xinjiang, China.

Many of the anticlines exposing Late Cenozoic sedimentary rocks on the north side of the Tien Shan are actively growing. River terraces are clearly warped over the anticlines with the oldest terraces warped most and successively younger, incised terraces warped less, thus offering the unique opportunity to determine incremental growth rates. Surveys of the two youngest major terraces in valleys crossing two widely spaced anticlines are warped up about 10-30m and 60-120m above regional surfaces. In one valley, older terraces stand higher with differences in elevations of about 100m. We assume that the older terraces were incised when aggradation gave way to rapid degradation. The heights of the terraces are crudely proportional to the ages of glacial maxima and to the times of rapid warming that followed them. Thus, we suspect that rates of uplift of crests, with respect to flanks, of anticlines are about 1mm/a. These rates and balanced cross sections across the anticlines imply initiation of folding in Pleistocene or latest Pliocene time and imply a convergence rate across the north flank of the Tien Shan of a few millimeters per year.

primarily a function of the crust/lithosphere thickness ratio z_{cr}/z_{li} (contrary to a common misconception among geochemists, the slightly lower intrinsic density of continental vs. oceanic crust plays only a minor role in determining the greater buoyancy of continental *lithosphere*). Aside from early "magma ocean" phases (when $z_{cr}/z_{li} \blacksquare 1$), z_{cr} is probably weakly dependent on T, but sensitive to the planet's pressure-depth gradient dP/dy, which governs the fate of Al during deep melting/crystallization processes. In planets with large dP/dy, most of the Al that would otherwise contribute to crustal feldspar instead remains buried in mantle garnet (or majorite, or other high-pressure phases). This is almost certainly the main reason why the crust of the Earth is thinner, even in absolute terms, than the crust of the far smaller Moon. A key implication is that during the course of planetary evolution, z_{cr} and z_{tcl} tend to remain relatively fixed, while z_{li} steadily increases due to cooling. Growth curves for the Moon's z_{cr} and z_{li} through time are constrained by studies of "pristine" rock ages (for z_{cr}) and tectonic features along the margins of mare basins (for z_{li}). The Moon has probably always had z_{cr}/z_{li} too high, or in later times z_{li}/z_{tcl} too high, to engender plate tectonics. Conceivably plate tectonics operated over the first few m.y. of the Moon's evolution, provided that it formed "cool" with a substantial lithosphere and yet a low z_{cr}/z_{li} ratio, which only later became prohibitively high, as the outer Moon came to resemble a "magma ocean." However, weighing heavily against this scenario are the consistently moderate to young (by lunar standards) ages of lunar granitic rocks: almost all 3.9-4.1 Ga.

05:15 p.m. Norman, M. D. № 31094

ORIGIN OF THE EARTH AND MOON BY ACCRETION OF DIFFERENTIATED PLANETESIMALS FROM RESTRICTED REGIONS OF THE SOLAR NEBULA

NORMAN, M.D., Planetary Geosciences Division, SOEST, University of Hawaii, Honolulu, HI 96822 U.S.A.; and TAYLOR, S.R., Research School of Physical Sciences, ANU, Canberra A.C.T. 2601 Australia

Sufficient compositional similarities exist between the Earth and Moon to build a case for a common origin. Oxygen isotopic compositions of igneous rocks from the Earth and Moon fall along a common fractionation line. Depletions in V, Cr, and Mn abundances relative to CI normalized values have been inferred for both the primitive terrestrial mantle and for the Moon. Estimates of the bulk composition of the Moon and the Earth's mantle show comparable relative abundances of Li, a moderately volatile element, and the more refractory HREE. These geochemical features distinguish the Moon and Earth from the parent bodies of differentiated meteorites and Mars.

Convincing compositional differences between the two bodies also exist so that the Moon cannot be simply a sample of the terrestrial mantle, spun off or ejected during large impact events. A major difference between the bulk compositions of the two bodies is the approximately 50% higher abundance of FeO in the Moon compared to the primitive Earth's mantle. V, Cr, and Mn depletions similar to those in the Earth and Moon are also observed in some classes of chondrites (CV, CM, CO), so that such signatures are related neither to planetary size nor to processes of planetary differentiation. The Moon appears to be enriched relative to the terrestrial mantle in refractory elements such as Ca, Al, and the REE, and is depleted in volatile elements such as K, Na, and Rb. However, these depletions are not always related simply to measures of volatility such as condensation temperature or boiling point.

Observations and model results show that planets accreted via a hierarchy of planetesimals, and that collisions between planet-sized bodies almost certainly occurred during the later stages of accretion. If the Moon was created by a 'giant impact' during the later stages of planetery accretion, physical models apparently require a very large proportion of the Moon to have been derived from the impactor. The relatively low collision velocity necessary to create the Moon via such a process, and the tantalizing compositional similarities between the Moon and Earth, suggest that both the Earth and the proposed impactor probably accreted from a restricted feeding zone. If so, the impactor was almost certainly a volatile-depleted, differentiated body as these characteristics seem to have been endemic to planetesimals within the inner solar system.

SESSION 147, 1:30 p.m.
WEDNESDAY, OCTOBER 23, 1991
TECTONICS V: EUROPE AND ASIA
SDCC: Room 14AB

01:30 p.m. Tari, Gabor № 5617

CONTRASTING STYLES OF EXTENSION IN THE PANNONIAN BASIN.

TARI, Gábor, Rice University, Dept. of Geology and Geophysics, P.O. Box 1892, Houston, TX 77251; RUMPLER, János, Geophysical Exploration Company, 1068 Budapest, Gorkij fasor 42, Hungary; HORVÁTH, Ferenc, Eötvös University, 1088 Budapest, Kun Béla tér 2, Hungary.

Based on structural interpretation of reflection seismic data, certain areas can be delineated in the Pannonian basin system which are characterized by distinct modes of upper crustal extension. Deep (>8 km) subbasins such as the Great Hungarian Plain and the Danube basin were largely extended during the middle Miocene syn-rift phase. In these areas extension was accommodated largely by low-angle detachment faults, inherited from earlier Alpine overthrust planes. It is proposed here that the large amount of extension is responsible for the occurrence of locally high-grade metamorphic rocks in the pre-Tertiary basement. The highly extended regions might have formed in a way similar to that of the well-known metamorphic core complexes in the western U.S., indicating extension magnitudes up to 300%.

In other regions of the intra-Carpathian area extension was accommodated by only planar normal faults rotated to different degrees indicating relatively little extension. The kinematic role of numerous strike-slip faults , observed on reflection seismic profiles as flower structures, is the connection of areas characterized by different amounts of extension. Moreover, since these strike-slip faults in some cases bound basin units with not only different magnitude but also with different polarity and direction of extension, we consider them as transfer faults. In the Pannonian basin the tectonic "pre-conditioning" of its Alpine basement is a key element in the localization of not only low-angle normal faults, but also in the spatial distribution of strike-slip fault zones. In many cases Neogene strike-slip faults which form characteristic flower-structures in the sedimentary basin fill, merge into low-angle or subhorizontal decoupling surfaces in the pre-Tertiary basement.

The very heterogeneously distributed and radial nature of extension in the Pannonian basin can be explained in terms of gravitationally driven extensional collapse of an overthickened and therefore unstable crust. In this scenario the opening of middle Miocene basins in the Pannonian basin system was driven by the extensional collapse of Eoalpine nappe-systems. The compressive boundary conditions were relaxed for these overthickened units after a large-scale late Oligocene/early Miocene episode of continental escape, disintegrating a more or less continuous Eoalpine thrust-and-fold belt.

01:45 p.m. Montanari, Alessandro № 31649

TECTONIC IMPLICATIONS OF A SARDINIAN PROVENANCE FOR AQUITANIAN TEPHRA IN THE PELAGIC BASIN OF THE NORTHEASTERN APENNINES (ITALY).

MONTANARI, Alessandro, Dept. of Geology and Geophysics, U.C. Berkeley, CA 95720, COCCIONI, Rodolfo, Ist. di Geologia, 61029 Urbino, Italy, CAREY, Steven, Grad. School of Oceanography, U.R.I., Kingston, R.I. 02881, DEINO, Alan, Geochronology Center, I.H.O, 2453 Ridge Rd. Berkeley, CA 94709, ALVAREZ, Walter, Dept. of Geology and Geophysics, U.C. Berkeley, CA 95720.

During the Tertiary, the northeastern Apennines of Italy functioned as a quiet depositional basin for fine-grained, air-fall volcanic ashes from distant explosive volcanism accompanying the Alpine/Apennine orogenesis. These ashes have been dated by several authors with different radioisotopic methods in the past decade (K/Ar, $^{40}Ar/^{39}Ar$, and Rb/Sr on biotite separates, $^{40}Ar/^{39}Ar$ single-crystal laser fusion on plagioclase and sanidine, and U/Pb on zircon), and provide the means for a precise, accurate age calibration of the Tertiary magnetostratigraphic, and biostratigraphic time scales. However, the provenance of these tephras has remained uncertain. To resolve this problem, we have carried out detailed grain-size analysis of the so-called "Livello Raffaello", a feldspar-bearing bentonite recognized in numerous outcrops throughout the region at the very base of the Bisciaro formation.

The Raffaello, stratigraphically located in the upper part of zones N4 and NN1, upper Chron 6A-r (middle Aquitanian), yelded an isochron age of 21.2 ± 0.5 Ma (2 σ) from 27 $^{40}Ar/^{39}Ar$ dates by laser fusion on plagioclase. We measured the mean grain size (MΦ) of the >63 μm felsic fraction (i.e. feldspar and quartz) of the Raffaello in 11 representative outcrops in the region, and compared the grain sizes against distance from two possible volcanic sources: the Venetian province (northern provenance), and the Sardinian province (western provenance). While the Venetian source shows no distinct trend of the MΦ distribution, the Sardinian plot exhibits a very clear linear grain size decrease with distance.

After having tentatively established a Sardinian source (no other volcanoes of Aquitanian age are known west of the Apennine basin), we revised the MΦ distribution through palinspastic restoration, including the post-Aquitanian anticlockwise rotation of the Sardinian microplate, and consequent orogenic shortening of the northeastern Apennine fold-and-thrust belt. For this, we have used the "thick-skinned" model of Lavecchia et al. (1984), which envisions a shortening for the northeastern Apennines of 3 to 30 km, and the "thin-skinned" model of Bally et al. (1986), with a variable shortening of 50 to 300 km. We have also modelled the distribution of the largest felsic crystals for modern-analogue stratospheric westerly winds blowing in this region, from fall to spring, at speeds of 10 to 30 m/sec, which account for distal (> 400 km) transport of fine tephra. Our preliminary results indicate that restoration by the thick-skinned setting yields a crystal size-distribution gradient incompatible with that predicted by the computed model, whereas restoration using the thin-skinned structural setting yields good agreement with that of the computed model.

02:00 p.m. Chaimov, Thomas A. № 24463

INVERSION TECTONICS IN THE INTRACONTINENTAL PALMYRIDE FOLD BELT OF CENTRAL SYRIA

CHAIMOV, Thomas A., BARAZANGI, Muawia, SEBER, Dogan, Institute for the Study of the Continents and Department of Geological Sciences, Cornell University, Ithaca, NY 14853; **AL-SAAD, Damen, SAWAF, Tarif,** and **KHADDOUR, Mohammed,** Syrian Petroleum Company, Ministry of Petroleum and Mineral Resources, Damascus, Syrian Arab Republic.

As part of an ongoing joint study between Cornell University and the Syrian Petroleum Company, over 1000 km of industry seismic reflection data from the Palmyride fold belt in the northern Arabian platform in Syria were interpreted to (1) improve subsurface structural maps by constructing a 3-D data cube on a Landmark workstation and (2) estimate the magnitude and timing of Palmyride deformation. The seismic data were supplemented by surface geology, Bouguer gravity and well data.

The NE-striking Palmyrides extend for approximately 400 km between the left-lateral Dead Sea transform fault system in Lebanon and the Euphrates depression in eastern Syria and are sandwiched between the more stable Aleppo plateau to the north and the Rutbah uplift to the south, the northernmost extent of the stable Arabian platform. Structural mapping in the southwestern sector of the Palmyrides elucidates the following structures indicative of inversion of the Mesozoic Palmyride failed rift: short en echelon folds and reverse faults linked by WNW-trending, left-lateral transfer faults. Seismic stratigraphic analysis indicates that inversion has taken place intermittently since Late Cretaceous time, probably as a response to the Late Cretaceous-present collision between the Arabian and Eurasian plates. Total shortening across the Palmyrides is relatively small; balanced cross sections show only 20-25 km of shortening in the most strongly deformed southwestern sector and a rapid decrease in shortening northeastward along strike of the belt. Discontinuous accumulations of mostly Triassic salt have allowed detachments to develop locally, but no regional décollement is apparent in the Phanerozoic sedimentary section of the Palmyrides.

On a regional scale, the main Palmyride fault zones, e.g., the frontal thrusts and the E-W trending Jhar fault that dissects the Palmyrides, exhibit a component of right-lateral strike slip superimposed on reverse faulting, indicating an overall right-lateral shear on the Palmyrides and arguing against explaining the Palmyrides as a "leak" of left-lateral slip from the nearby Dead Sea fault system. This right-lateral shear together with decreasing magnitude of shortening along strike of the belt towards the Euphrates depression implies that a local pivot point exists near the Euphrates-Palmyrides intersection. Hence, relative to the Aleppo plateau, the stable Rutbah uplift appears to be rotating clockwise around this pivot, perhaps indenting the Dead Sea fault system in southern Lebanon and contributing to rifting in the southern Euphrates graben system.

ABSTRACTS WITH PROGRAMS, VOL. 23, NO. 5, 1991 ANNUAL MEETING, ISSN 0016-7292

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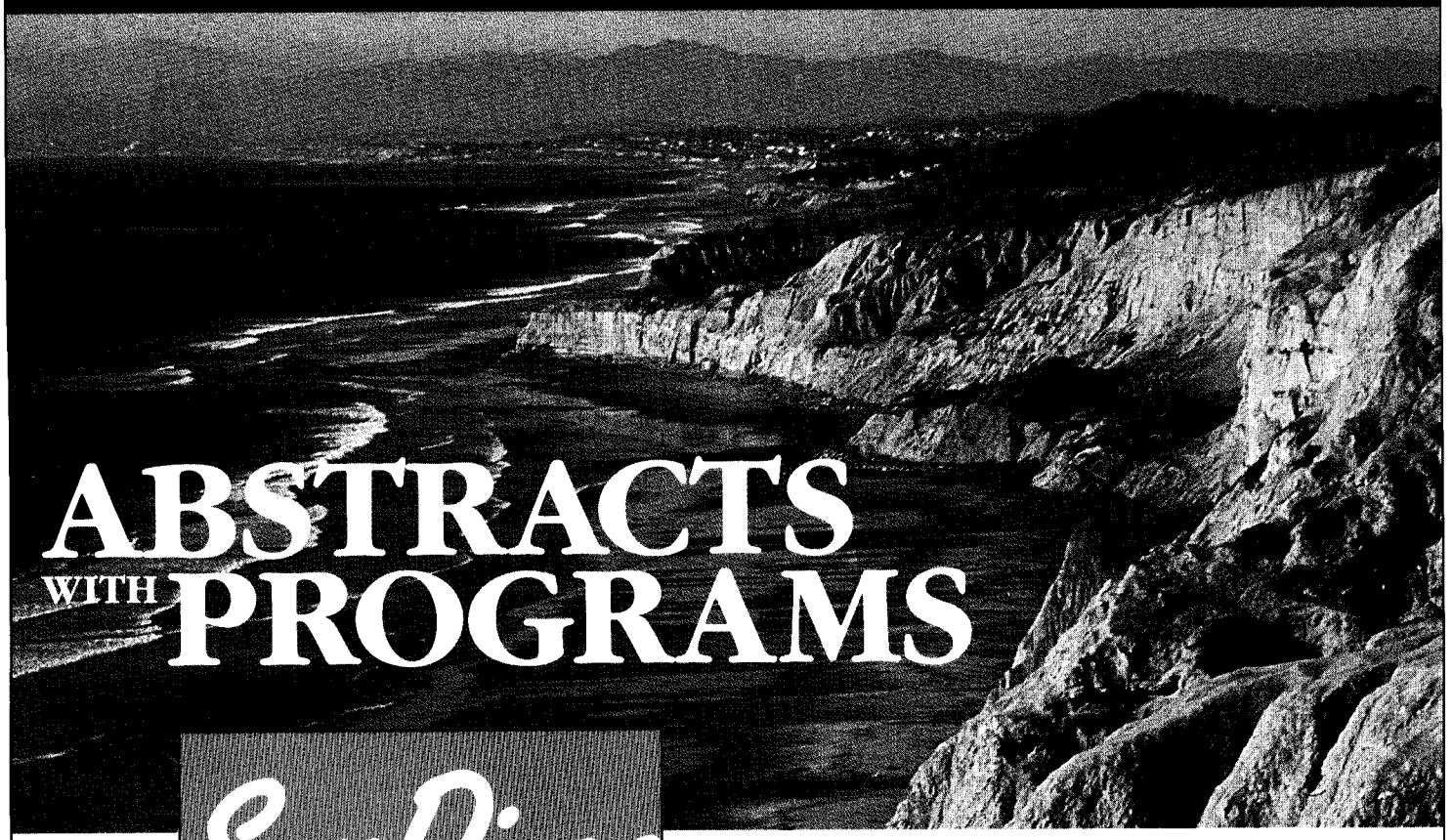

ABSTRACTS WITH PROGRAMS

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