the result of transport of both phase 2 footwall and hangingwall sequences over a NE-trending lateral ramp along a deeper level detachment. An open, phase 2 syncline at the northern edge of the Fenghuoshan is intruded by a post-kinematic hypabyssal biotite syenite from which a 31 Ma K-Ar age has been reported (Harris et al. 1988). This indicates deformational phases 1 and 2 occurred prior to the end of the Early Oligocene. Phase 3 involves S-vergent thrusting of Eocene over Plio-Pleistocene sediments along the S flank of the range.

4:30 PM Youshe, Li

SHORTENING WITHIN THE NORTHERN LHASA BLOCK AT CA. 90OE–ASSESSING STRAIN CONTRIBUTIONS FROM THE INDIA-ASIA COLLISION

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GeDepth / INDEPTH III surface geology investigations were conducted upon the tibetan plateau in the northern half of the Lhasa Block (30o30' to 31o15' N, and 89o45' to 90o15' E). Our work includes structural mapping, fault kinematic analyses, geochronology and palaeomagnetic studies, encompassing a section from immediately south of the ESE-trending en echelen dextral wrench faults of the Karakoram-Jiali system (the syntaxes' chord) to immediately north of the Zagya Tsangpo (adjacent to the Bangong suture trace). The prevalent stratigraphy comprises folded and thrust, mainly Cretaceous-age limestones with red and dark sand-, silt-, and mudstones interlayered with volcanics. In the northern portion of the traverse, structurally imbricated are volcanics, associated volcaniclastic sediments, and cherts of likely ophiolitic/island arc type affinity. In the southern portion, Permian and older Mesozoic rocks are thrust N-wards upon the Cretaceous. Locally scattered throughout the section are 100's m thick, S-ward thrust slices of serpentinised peridotite and other ophiolitic rocks; they are part of the Jurassic-emplaced Dongqiao obduction "nappe" that extends for >150 km south from the Bangong Suture (Girardeau et al. 1984). In the main Cretaceous section, folding is open to tight and, where thrust displacements are constrainable via stratigraphy, shortening amounts are 30-60 %, unevenly distributed along a bulk NNE axis. A range of K-Ar ages from interbedded volcanic rocks from Aptian to Campanian requires the shortening to be latest Cretaceous if it pre-dates the India-Asia collision (as suggested by Murphy et al. 1997 - for a similarly located section at ca. 85oE). In the northernmost portion of the traverse, a ca. 15 km section at Zagya Tsangpo comprises tightly folded red-beds complexly overthrust from the south by blocks (+melange?) of ophiolitic rocks. Palaeomagnetic results indicate an anti-clockwise rotation (left lateral sense) about the trace of Bangong suture. We infer N vergent reverse local fault reactivation of the suture. Based upon both the marine facies of the adjacent Aptian - Campanian rocks and nearby reports of late Cretaceous seaway rocks, this reactivation must be due to the India-Asia collision.

4:45 PM Treloar, Peter J.

EXHUMATION OF EARLY TERTIARY, COESITE-BEARING ECLOGITES FROM THE KAGHAN VALLEY, PAKISTAN HIMALAYA

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The preservation of coesite in ultra high pressure eclogites now at surface raises questions about the structural mechanisms by which they were exhumed. As UHP rocks metamorphosed early in an orogenic cycle probably come to surface through more than one exhumation phase, often few structures remain that relate to the early part of the exhumation path that brought them to "mid"-crustal depths. Here, part of that early path is revealed for coesite-bearing eclogites from the Indian Plate internal zones of N. Pakistan. Metamorphism, at 725 ± 25°C, 28 - 30 kbar, at c. 50 Ma, shortly post-dated subduction of the leading edge of continental India beneath Kohistan.

Structural restorations, field and petrographic data, show the eclogite-bearing rocks are flanked by thrusts below and extensional shears above and that thrusting, extension and the amphibolite to greenschist facies transition were synchronous. The eclogites lie immediately above a top-side-S thrust, S-C' fabrics related to which are overprinted by greenschist facies albite porphyroblasts. The dominant microstructures, though, are S-C' shear bands, penetratively developed throughout the eclogite facies metasedimentary sequences, which document a phase of pervasive top-side-N extension. Hornblende crystals locally parallel stretching lineations related to this extension. Albite porphyroblasts up to 10 cm in diameter overgrow extension related fabrics, although elsewhere they are flattened and stretched within those fabrics.

Top-side-S thrusting predated cooling through the amphibolite greenschist transition at 40 Ma, at which time the pervasive top-side-N extension was operating. This implies exhumation from metamorphic peak to greenschist facies within a few million years. It is likely that both the thrust and extensional sense shear zones represent the late-stage of a deformation continuum which commenced at UHP and brought the eclogites back to "mid" crustal levels. Subsequent Miocene extension brought the rocks near to surface.

5:00 PM Terry, Michael P.

EVIDENCE FOR THRUST IMBRICATION OF BALTICA BASEMENT, AND SYN-COLLISIONAL EXHUMATION OF HIGH-PRESSURE ROCKS, WESTERN GNEISS REGION, NORWAY

TERRY, Michael P., Geology, Bowdoin, Brunswick, ME 04011, mterry@Bowdoin.edu, BINGEN, Bernard, Geological Survey of Norway, Trondheim, N-7491, Norway, and ROBINSON, Peter, Geol Survey of Norway, Trondheim, N-7491, Norway

Integration of tectono-stratigraphic, geochronologic, structural, and petrologic data from the central and southern parts of the Western Gneiss Region (WGR) leads to better understanding of exhumation processes for high-pressure rocks. In the south, the Lindås Nappe lies structurally above an extensional fault and was subject to eclogite-facies metamorphism. New ion probe results indicate that the lower intercept age of 419 ± 4 Ma was the time of eclogite-facies metamorphism that overprinted an earlier Sveconorwegian granulite-facies metamorphism (929 ± 1 Ma). These results indicate that Sveconorwegian Baltica basement originally lying outboard of the present WGR was subducted to a depth of 65 km, imbricated, and later thrust toward the foreland and exhumed through amphibolite-facies conditions, possibly at 409 Ma. A repetition of similar events occurred in UHP rocks in the central part of the WGR, including microdiamond-bearing kyanite-garnet gneiss and associated kyanite eclogites. UHP rocks show thrust kinematics under eclogite-facies conditions that occurred from 407 ± 2 to 402 ± 2 Ma. These UHP rocks are interpreted to have been imbricated and brought in contact with HP basement by thrusting between 402 and 395 Ma. The age range for UHP metamorphism overlaps with the deposition of sediments in the high-level Hitra extensional basin over a minimum range of 403 to 394 Ma. Monazite grains from the microdiamond-bearing kyanite-garnet gneiss also contain interior domains, possibly detrital, that yield ages near 1060 Ma, interpreted to reflect an earlier Sveconorwegian metamorphic event that took place outboard of the WGR. Implications: 1) Syn-collisional exhumation was the primary mechanism for exhumation of HP and UHP rocks from 419 to 395 Ma. It was accomplished by synchronous deep thrust imbrication and upper crustal sinistral trans-extension along a sinstral transpressive plate boundary. 2) Sveconorwegian basement was present west of older 1500 to 1680 Ma basement gneiss. 3) Imbrication of HP Baltica basement and cover into relatively thin tectonic units indicates that models invoking imbrication of entire crustal thicknesses are not applicable to the Scandinavian Caledonides.

5:15 PM Brueckner, Hannes K.

"DUNK" TECTONICS AS A MODEL FOR THE EVOLUTION OF THE SCANDINAVIAN CALEDONIDES

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Mountain systems evolve through multiple collisions involving continents, microcontinents, arcs, ocean plateaus etc. before the terminal continent-continent collision that ends the Wilson Cycle. Some collisions occur through the subduction and buoyant return (eduction) of crustal slabs, a process provisionally called "dunk" tectonics. Dunked slabs are recognized as high-grade metamorphic terranes bounded by thrust faults at the base and low angle normal faults at the top. Some slabs are subducted into the mantle where they are invaded by peridotite from the overlying mantle wedge. The presence of peridotite masses are diagnostic of deeply subducted terranes. Variables such as the rate, angle and depth of subduction, "hang-time" in the mantle, and exhumation rate determine the nature of metamorphism and deformation, the degree of retrogression, and the mineralogy of the introduced mantle fragments. Slabs that reach deep mantle levels (>60Km) are metamorphosed under high pressure (HP) conditions to form eclogite-facies terranes. Extreme subduction (>120 km) results in ultra high pressure (UHP) metamorphism. The evolution of the Caledonides of Scandinavia included three and probably more events of crustal subduction that resulted in HP and UHP eclogite-facies assemblages accompanied by the introduction of mantle peridotite. Two are the classic Finnmarkian (arc-continent) and Scandian (continent-continent) orogenies at ca. 500 and 410 Ma. We present evidence for a third HP event at ca. 455 Ma that involved the subduction of the western edge of Baltica beneath a microcontinent. We suggest that other orogens such as the Alps and Himalayas would be better understood through dunk tectonic mechanisms.

SESSION NO. 138, 1:30 PM

Wednesday, November 7, 2001

K7. The Watershed Within: Scientific and Moral Reflections on Water in the 21st Century (*Critical Issues Subcommittee of Geology and Public Policy; GSA Quaternary Geology & Geomorphology Division; Institute for Earth Science and the Environment*)

Hynes Convention Center, Ballroom B

1:30 PM Fisher, George W.

SCIENTIFIC AND MORAL REFLECTIONS ON WATER USE AND ALLOCATION

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The great human project of the next century will be learning how 10 or 12 billion people can live fruitfully and sustainably on a finite Earth. Questions of water use and allocation will be among the many contentious dimensions of the sustainability discussion. During the last century, global water consumption grew more than twice as fast as population. Roughly one-third of the world population now lives in areas subject to moderate to high water stress, and the U.N. projects that the proportion of people affected could double during the next 25 years. Allocation of water among countries bordering rivers like the Jordan, the Nile, and the Colorado is a source of international tension. Allocation of water between agriculture, manufacturing, household use, and ecosystem maintenance are politically sensitive issues that will impact food availability, human health, and culture.

To be effective, policy discussions on water use must consider issues of availability, efficiency, human equity, needs of ecological systems, and the well-being of future generations. To be seen as fair, they must involve the principal stakeholders. Negotiating this complex of competing needs and interests requires both a scientific understanding of how water resources are sustained and used and a moral understanding of how different participants value water and understand the notion of equity.

A full discussion of water use must therefore incorporate both scientific and moral reflection on water availability and allocation. Finding ways of connecting a scientific understanding of how the world works with a moral understanding of how humans ought to live has proven difficult, but is a vital part of the sustainability problem. We hope that exploring these aspects of water use will be helpful in understanding how best to approach the larger issue of sustainability.

1:45 PM Wolman, M. Gordon

WATER AND LIVES

WOLMAN, M. Gordon, Johns Hopkins Univ, 3400 N Charles St, Baltimore, MD 21218-2608, wolman@jhu.edu

Most people live in one of two worlds, not simply one. Infant mortality in the poor world is 62/100,000; leading causes of death and sickness are diarrheal and infectious diseases and malaria. All are water related. In the other world, children's deaths are 9/100,000 live births; leading causes of death are heart disease, cancer and stroke. Water is central to this disparity. Roughly 1.5 billion people, about 20% of the world's population, lack adequate drinking

5:15 PM Panhorst, Terry L.

INFLUENCE OF PRE-EXISTING JOINTS ON STYLE OF DEFORMATION RELATED TO LACCOLITH DEVELOPMENT, TENT CANYON DONE, WYOMING

PANHORST, Terry L., Department of Geology & Geological Engineering, Univ of Mississippi, 118F Carrier Hall, University, MS 38677, panhorst@olemiss.edu

Laccolith development in sedimentary rocks includes brittle deformation of the overlying units typically by warping of beds and faulting. Physical laboratory models of dome formation have suggested radial fracture orientations developing in unfractured overlying materials for a circular dome or fractures developing along a preferred trend parallel to the long axis of an elliptical dome. Pre-existing joints will likely influence the nature of deformation and accommodate a significant amount of deformational response to a doming event. Tent Canyon Dome, a shallow elliptical laccolith in the Black Hills of Wyoming, exhibits deformation concentrated along pre-existing joints. Jointing in more competent lithologies can mostly be attributed to deformation prior to doming, indicating that few new fractures were developed during laccolith emplacement. Tilting and faulting were the dominant responses to the doming event, both of which utilized existing joints. Thinning of a weaker shale unit between more competent limestones and sandstones accompanied stretching of overlying units.

Parts of the Tent Canyon Dome sedimentary roof rocks broke into fault-bounded blocks, each showing a unique orientation of tilting. Bedding orientations exhibit restricted variability within individual blocks and distinct differences in the average orientations compared to adjacent blocks. Presence of these areas of relatively uniform dip suggests each block of overlying sedimentary rock acted as a somewhat coherent plate, rising and tilting as a rigid mass rather than having gradual changes in dip amount by warping. Pre-existing joints allowed the overlying sedimentary units to deform mostly by tilting of these blocks rather than internal deformation by warping. Less tilting appears associated with bounding faults along the northeastern periphery of Tent Canyon Dome, where deformation was accomplished mostly by fault displacement.

SESSION NO. 137, 1:30 PM

Wednesday, November 7, 2001

Tectonics II: Fold-Thrust Belts and Collisional Processes

Hynes Convention Center, 302

1:30 PM Gilbert, Oscar E.

STRUCTURAL GEOLOGY AND REGIONAL TECTONICS OF THE CHITTAGONG HILLS FOLD BELT, EASTERN BANGLADESH

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The Chittagong Hills fold belt of eastern Bangladesh represents the less intensely deformed foreland of the Indo-Burman Ranges. Exposed stratigraphy consists of Miocene prodeltaic mudstones overlain by tidal-influenced mudstones and sands of Miocene to Pliocene age. The coarsening-upward sequence suggests basinward progradation of deltaic sedimentation. Sediment transport fabrics indicate a northeasterly (southeast Asian) source terrane.

Major structures are box-fold anticlines with broad crests and steeply dipping to overturned limbs, and broad flat-bottomed synclines. Limbs of anticlines are locally thrust-faulted, with thrusts vergent toward both the east and west; features such as the Changohtong - Sitapahar Anticline exhibit thrusts along both flanks. Secondary structural features include minor tear faults indicative of minimal lengthening of the anticlines along strike.

To the east the fold belt is bounded by the Thega Fault and the tightly-imbricated, thrust sheets of the main ranges. To the west the folds die out rapidly along a boundary approximately coincident with the present coastline, and its onshore extension into the Ganges-Brahmaputra Delta. Non-proprietary seismic and well data indicate that west of this line anticlines are broad, low relief structures.

The detachment surface is approximately four kilometers below the present ground surface. Unlike most foreland fold-thrust belts, the regional detachment surface dips toward the foreland at about one degree. This west-dipping detachment is interpreted as the roof thrust of a crustal-scale duplex, above which exposed strata are detached from an underlying west-vergent accretionary prism involving Cretaceous to Oligocene(?) sediments scraped off the Indian plate.

To the north the Tripura - Cachar – Chittagong fold belt plunges into the deep Assam Basin. To the south the detachment rises, and progressively deeper parts of the fold system are exposed in the Bangladesh – Myanmar border regions. The absence of significant strike-slip faults indicates that strain across the plate boundary is partitioned. The fold belt accommodates simple east-west convergence, while the relative southward translation of the major Southeast Asian Plate is accommodated by strike slip along discrete faults like the Sagaing Fault of central Myanmar.

1:45 PM Echavarría, Leandro E.

SUBANDEAN THRUST AND FOLD BELT OF NORTHWESTERN ARGENTINA. GEOMETRY AND TIMING OF THE ANDEAN EVOLUTION

ECHAVARRÍA, Leandro E., Conicet-Cornell Univ, Department of Earth & Atmospheric Sciences, Snee Hall, Cornell University, Ithaca, NY 14853, lee3@cornell.edu, HERNÁNDEZ, Roberto M., XR Consulter, Manzana N casa 14, Barrio Parque Gral. Belgrano, 1ra Etapa, Salta, 4400, Argentina, and ALLMENDINGER, Richard W., Cornell Univ, Department of Earth & Atmospheric Sciences, Snee Hall, Cornell University, Ithaca, NY 14853

The Subandean belt of the central Andes is one of the premier thin-skinned thrust belt belts of the world, as well as the prime example of such a belt in a retroarc, non-collisional setting. Understanding of the Subandean, however, has long been hampered by the lack of detailed knowledge of the ages of motion of individual thrust plates. Such information, however, is critical for hydrocarbon exploration as well as for comparison with modern geodetic GPS data, and evaluation of seismic hazard. New field, seismic reflection, and geochronological data from NW Argentina put this part of the Subandean belt in the same league as the very best dated thrust belts of the world.

The decollement for the southern Subandean belt dips 2-3°W and lies mostly within Silurian shales. However, a unique aspect of the belt is an intermediate detachment level in thick Devonian shales. Below this horizon structures are relatively simple fault-bend folds whereas above, vertical limbed lift-off structures are decoupled from the underlying sequence. At 22°-23°S, we have documented ~60 km of shortening; about 65% occurred in sequence from west to east, whereas the remaining 35% is out-of-sequence.

Subandean belt timing has been determined by magnetic reversal stratigraphy, tephra chronology, unconformities and growth strata geometries in foreland basin strata. An increase in the accumulation rate in the western part of the foreland basin at about 8.5-9 Ma marks the onset of Subandean deformation when a crystalline basement thrust plate to the west ramped up to the current decollement level. Using vertical separation diagrams, we pinpoint the initial uplift of the Pintascayo Range at 7.6 Ma and the Baja Oran Range at ~6.9 Ma; both were active simultaneously until at least 4.7 Ma. To the east initial deformation is younger: in the San Antonio Range fault movement began at 4.4 Ma, and the Aguaragüe uplift started at ~2.8 Ma. Since 4 Ma, new and reactivated thrust faulting characterizes almost all the Subandean Ranges, especially after 2 Ma. In concert with the balanced sections, these results suggest shortening rates varying from less than 5 to as great as about 10-12 mm/a over the last 10 Ma.

2:00 PM Picornell, Carlos M.

THE PAMPLONA FOLD AND THRUST BELT, GULF OF ALASKA: CONTRACTION IN AN EVOLVING OROCLINAL BEND AT THE SUBDUCTION-TRANSFORM TRANSITION OF THE EASTERN ALEUTIAN ARC

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The Pamplona zone is the deformation front of an active fold-thrust system developed at the leading edge of the Yakutat microplate during collision of the microplate with the eastern end of the Aleutian trench. Published geodetic and Quaternary geology studies onland suggest that the Yakutat microplate is converging with North America at essentially full North America-Pacific velocity, and thus, if the Pamplona zone were a typical fold-thrust belt it should be absorbing most, or all, of this convergence. This is clearly not the case. Using public domain and industry seismic data from the offshore segment between Icy Bay and the central part of the Pamplona zone, we produced balanced cross-sections across the two leading anticlines of the fold-thrust belt. Age control is limited, but two offshore exploration wells provide sufficient information to place at least approximate control on the timing of fold development through analysis of growth strata on the fold limbs. Analysis of growth strata suggest little, if any, hinge migration and folding via a detachment fold mechanism. Restoration of these folds indicates only 1km of shortening across these structures. At full North America-Pacific convergence rates this amount of contraction could have occurred within the last 20 Ka, yet the growth strata demonstrate that the folds developed over at least 600,000Ka. Thus, the Pamplona zone is absorbing only a small fraction, if any, of the direct convergence of Yakutat microplate. Instead, we suggest that most, or all, of the present contraction is either occurring onland or to the west in the Kayak Island zone; a band of previously recognized deformation that extends northeastward from the Aleutian trench into the core of the orogen. We interpret the Pamplona zone as a secondary effect of ?oroclinal bending?. In this model the Pamplona zone is produced in the contractional ?inside corner? where the Yakutat microplate is oroclinally bent as it is driven into the subduction-transform transition and forced to mould to the backstop. This model implies significant strike-slip within the core of the orogen along the Bagley-Seward glacier trough, and may resolve the origin of the peculiar geometry of the Pamplona zone, which cuts obliquely across the topographic/bathymmetric grain of the orogen.

2:15 PM O'Sullivan, Paul B.

EVIDENCE AND IMPLICATIONS FOR OUT-OF-SEQUENCE STRUCTURES IN THE SADLEROCHIT MOUNTAINS REGION OF THE ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA

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Fission-track thermochronology and structural analysis constrain the timing and structural development of the Sadlerochit Mountains, located along the southern edge of the coastal plain in the Arctic National Wildlife Refuge (ANWR) of northeastern Alaska. Rocks exposed south of the Sadlerochit Mountains within Ignek Valley experienced two episodes of rapid cooling from elevated paleotemperatures at ~45 Ma and at some time since ~31 Ma, whereas similar-aged rocks exposed along the northern flank of the Sadlerochit Mountains cooled rapidly at ~45 Ma and ~27 Ma. Additional results from the Beli Unit #1 well, located northwest of the Sadlerochit Mountains, indicate that the sampled sequence experienced progressive heating during the Late Cretaceous to Early Cenozoic prior to cooling rapidly at ~45 Ma. Combined, the thermochronology results indicate that the Sadlerochit Mountains region experienced progressive heating up to Middle Eocene time, after which two major episodes of rapid cooling occurred in the Middle Eocene at ~45±3 Ma and in the Late Oligocene, at ~27±2 Ma.

These episodes of rapid cooling are interpreted to have occurred in response to km-scale erosional denudation, which resulted from uplift due to structural thickening during the emplacement of horses in a basement-involved duplex. Initially, at least one horse was probably emplaced to the north of the Sadlerochit Mountains at ~45 Ma. Subsequently, at ~27 Ma: 1) the Sadlerochit Mountains horse was probably emplaced behind the earlier emplaced horse(s), and thus was out of sequence, and 2) basement-involved deformation formed structures beneath the coastal plain to the north.

These results indicate that potential hydrocarbon source rocks in the vicinity were exposed to peak burial temperatures prior to Middle Eocene time, after which they experienced rapid cooling during the initial episode of structural deformation. Therefore, hydrocarbon generation from these source rocks probably occurred before formation of the structures in and immediately north of the Sadlerochit Mountains.

2:30 PM Bump, Alexander P.

THREE-DIMENSIONAL LARAMIDE DEFORMATION OF THE COLORADO PLATEAU: COMPETING INFLUENCES OF THE SEVIER THRUST BELT AND THE FLAT FARALLON SLAB

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Kinematic analysis of six Laramide basement-cored uplifts on the northern Colorado Plateau indicate that four of the uplifts (the Kaibab, Circle Cliffs, Miners Mountain, and Uncompahgre uplifts) were constructed by northeast-directed shortening while the remaining two (that San Rafael Swell and Monument Uplift) were constructed by southeast-directed shortening. Available timing data suggest that all of the uplifts rose at approximately the same time (~72-65 Ma; Lawton, 1983; Goldstrand, 1994), precluding the possibility that they formed sequentially in response to a progressive rotation of regional stresses.

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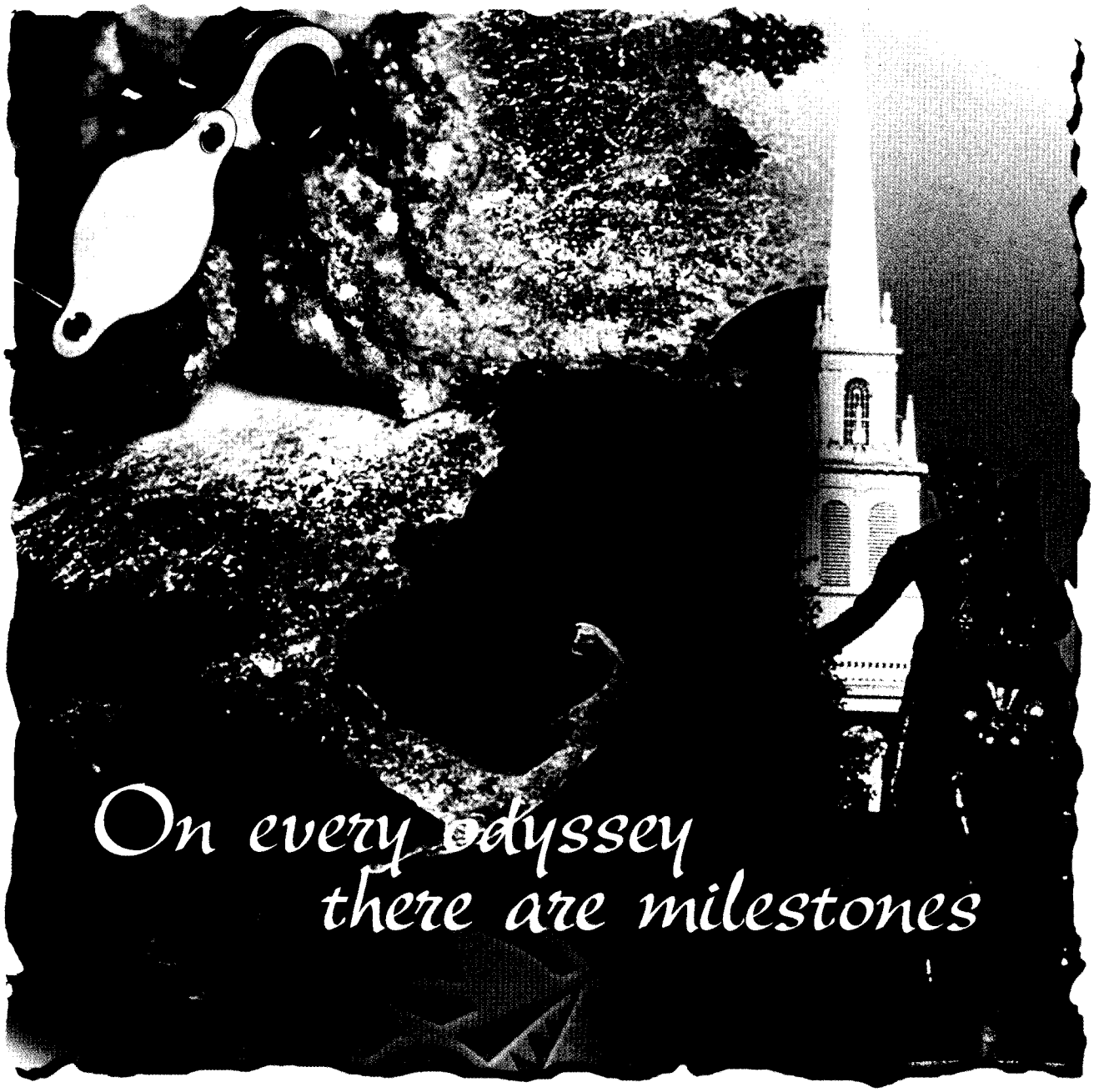

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