of certain sedimentary structures, ranging from clastic dikes and sandblows to large-scale subaqueous slides. Before 1971 clastic dikes and sandblows were the most commonly reported earthquake-induced structures. After the 1971 San Fernando, Calif. earthquake (M_L = 6.6), a zone of deformational structures associated with that event and two older zones of structures, including radially symmetrical load casts, heave-ups, and pseudonodules, were found in Van Norman Lake, 13 km from the epicenter. These deposits, as well as those at Pallet Creek, Calif. yield detailed data about earthquake recurrence. Other studies reveal similar structures in lake beds in Canada, Alaska, and Turkey. The structures occur in fine-grained lake beds at level or gently sloping sites with depositional rates of ~0.5-5 mm/yr. These structures may be upward or downward penetrative and in some cases mimic those in turbidites. Downward penetrative structures result from lateral flow of liquefied sediments and sagging of cohesive laminae. Upward penetrative structures result from localized high pore pressures and water ejection and rupture of confining laminae. X-ray radiographic study of the structures reveals a characteristic fabric produced by liquefaction, and criteria for field recognition of the structures has been proposed.

Earthquake-induced subaqueous slides are reported from a number of places. The most famous slide is related to the 1927 Grand Banks, Newfoundland earthquake, which resulted in broken submarine cables and turbidite deposits. Similar slides, in some places accompanied by submarine-cable breaks, occurred near Valdez, Alaska in 1898, 1908, 1911, 1912, 1925, and 1964. Turbidite deposits may have resulted from all these slides, but they have not been studied.

T31-7 INVITED

Deformed Lake Sediments Record Prehistoric Earthquakes during the Deglaciation of the Canadian Shield

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As the Wisconsin ice sheet retreated northward along the Ontario-Quebec border it trapped a glacial lake (Barlow-Ojibway). Annual silt and clay layers (varves) deposited in the lake as the ice melted were correlated (in 1925) across the lake by thickness variations into a 2075-year chronology (approx. 10,000-7900 yr.BP, by C^{14}). Zones of contorted varves occur within the evenly-bedded varves and are dated by the chronology to ±2 yr. Contortions at sites 160km apart are attributed to earthquake-shaking on the basis of 1) synchronous formation 2) large areal extent of deformation 3) sedimentary structures similar to those formed by earthquakes 4) crude regional pattern with greatest deformation at center.

The best example of synchronous deformation happened at 1487 varve-years (8500 yr BP) and affects a triangular region of 12,000 km^2 from Ville Marie and Macamic, Quebec to Porcupine, Ontario. The nature of deformation varies from place to place, but includes overturned folds, crumpled layers, small-scale faulting and thick layers of "homogeneous" clay. On some eskers post-deformation varves rest directly on sand or gravel, earlier varves apparently having slid away. Deformation is greatest along a NW-SE axis centered on Kirkland Lake, then ~ 80 km south of the retreating ice front. Assuming Modified Mercalli intensity VI is needed to disturb the sediments (vide Sims' California data), historic earthquake effects in eastern Canada suggest the earthquake had magnitude ≥ 5.7.

A section near Ville Marie with 3 contorted zones suggests that MM VI was exceeded thrice in 1150 yr. The study of such contorted zones in space and time can estimate the size, epicenter, and frequency of earthquakes during deglaciation and record the return period of a given shaking intensity at each place.

T31-8

Earthquake-Induced Sedimentary Deformational Structures, East Anatolian Fault, SE Turkey

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Exposures of lacustrine sediments fringing the shores of Lake Hazar contain up to three distinct horizons of soft-sediment deformational

overlie a presently active seismic zone— the East Anatolian Fault. A recent microseismicity study conducted near Lake Hazar has shown a

daily average of five earthquake events of magnitude 3 or less. Much larger earthquakes are known from the historical record. (2)The horizons are laterally extensive for hundreds of meters. (3)They are flat lying (dipping toward the lake at less than one degree). (4)They are separated by undeformed sedimentary beds. Individual horizons are 2.5 - 50 cm thick. (5)Deformational structures within the horizons are symmetrical (with no predominate vergence) and are very similar to liquefaction structures produced experimentally. They include circular ball-and-pillow structures, flat-bottomed ball-and-pillow structures, overturned folds, irregular waveforms, and detached 'pseudonodules'. (6) Deformational structures are found in sediments of high liquefaction potential. In all cases the structures are defined by the deformed contact between originally overlying coarse-grained silt and originally underlying clayey silt. Sparse structures such as 'exploded' pillar tops and large mushroom-shaped pillars suggest that minor fluidization also occurred.

These features suggest that the horizons of deformational structures were caused by liquefaction and minor fluidization induced by large earthquake shock.

T31-9

Coral Growth-Band Dating of Vertical Tectonism in Recent Decades, Vanuatu (New Hebrides) Arc

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Very shallow-water corals record the approximate time and amount of vertical tectonic movements in recent decades in the Vanuatu Arc. Recovery of this information is based on (1) coral growth-band dating using annual-type density banding in coral heads and (2) the sensitivity of growth rate and band density to slight changes in water depth for very shallow-water coral heads. *Goniastrea retiformis* is the main coral species being used. In some cases coral heads are partially emerged by tectonism and their top surfaces die recording uplift in the form of both coral morphology and thinner, denser growth bands. Response times of corals for uplifts >0.5m are on the order of days to months. Uplifts <0.1m may require a year to affect a coral noticeably. Subsidence effects are probably more subtle and no examples have yet been positively identified.

Coral growth bands show that the central Vanuatu islands, Santo and Malekula, have been uplifted several times in recent decades. Using corals, the uplift patterns for each event have been distinguished. S Santo, N Malekula, and part of SW Malekula were uplifted in association with a sequence of earthquakes in August, 1965. Uplift of SE Santo is associated with an October, 1971, thrust-type earthquake beneath SE Santo. NE Malekula has neither uplifted nor subsided more than one or two cm since 1966, although small post-seismic vertical movements following the 1965 uplift are possible. NW Santo was uplifted in association with the Dec-Jan 1973-74 thrust-type earthquakes in that area. Research is in progress to extend the chronology of paleoseismicity backward in time and to include other areas of the Vanuatu arc.

T31-10 INVITED

Large Strain Effects in the 1886 South Carolina Earthquake and Structures in the Sediments of the Coastal Plain

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The 1886 South Carolina earthquake was associated with a wide zone of liquefaction and large strain effects widespread in the Coastal Plain (C.P.) of South Carolina. These effects include systematic large horizontal strain, large dry fissures and changes in line-of-sight that seem to indicate large differential changes in elevation. Liquefaction-related phenomena, such as the ejection of water and sand from craterlets and the formation of sinks, were very strong in the Charleston-Summerville area, but were also

ments. A literature search and preliminary field observations reveal that several kinds of structures have affected the post-Late

Cretaceous sediments of the C.P. in the southeastern U.S. These structures include clastic dikes, clastic pipes, and localized folding and faulting. The pre-Late Cretaceous "basement" below the sediments of the Coastal Plain is capped by a fossil saprolite which consists of a clay rich impermeable layer meters thick and is probably mechanically distinct from rock units above and below. Some of the observed structures appear to be rooted in this layer or associated with ductile deformation localized to this layer. We conclude that the dynamic load of the 1886 earthquake caused deformations in a wide area of the Coastal Plain which can be expected to result in structures recognizable in an outcrop. Conversely, the different kinds of structures which are abundant in the same area may have formed during previous large earthquakes.

T31-11

Large Scale Patterns of Seismicity Before and After the 1886 South Carolina Earthquake

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Time-space patterns of seismicity with dimensions of several years and hundreds of kilometers can be identified in the southeastern U.S. from catalogues and archival data. During the 15 years preceding the 1886 earthquake, seismicity was low in S.C. and high in the surrounding areas, forming a "doughnut" pattern. Within a year and a half of the 1886 earthquake a persistent source of seismicity became active in the Piedmont of S. C. Within a week of the main shock on August 31, several earthquakes were felt in S. C. and Ga. Some of these were located near Charleston, but at least one seems closer to Augusta, Ga. A protracted period of high seismicity followed the 1886 main shock. According to catalogues these "aftershocks" are all located in Charleston-Summerville. Direct and indirect evidence suggest that they are distributed over a much wider area. Two more bursts of seismicity can be identified. One is between 1912-17, which contains the strongest earthquake of this century in each of S. C., Ga., N. C., and Tenn. The other is between 1956-59. In general, these bursts of seismicity effect the entire S. C.-Ga. seismic zone. No structure peculiar to this seismic zone has been identified. From these seismicity patterns and other evidence we suggest that the S. C.-Ga. seismic zone is itself a transient feature. These patterns may indicate rapid and widespread stress changes and mostly aseismic strain events. Such events would not be easily reconciled with an intraplate environment dominated by low strain rates on localized steeply-dipping faults scattered through the brittle part of the earth's crust, but could be reconciled with movement on reactivated Appalachian low-angle thrusts or detachments of regional dimensions.

T31-12

SEISMIC TRIGGERING AND EARTHQUAKE PREDICTION

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Observational evidence leaves little doubt that transient and episodic aseismic crustal movments occur in major seismic belts, and a convincing case can be made that some of these have induced stress changes which triggered large earthquakes. Seismicity induced by reservoir loading typifies the kind of triggering described here: imposed stress changes are small (~a few bars), and large shocks occur only if the causative faults are already rather close to failure. Episodic stress changes caused by magma-chamber inflation have triggered tectonic earthquakes in Japan (Izu Peninsula) and California (Mammoth Lakes), and postseismic transients from great plate boundary thrust earthquakes have induced large intraplate shocks on the Japanese mainland. Observed episodic movements can represent the equivalent of a decade or more of steady strain buildup, suggesting the importance of triggering in regions of

episodic deformation and emphasizing a probabilistic rather than deterministic approach to earthquake prediction.