

tute, University of Tokyo) described a deformation cycle for an earthquake comparable to the 1946 Nankai subduction earthquake (magnitude 8.1) based largely on leveling data.

Kazuaki Nakamura (Earthquake Research Institute, University of Tokyo) made the startling suggestion that northern Honshu belongs to the North American Plate. During the Pliocene, the plate boundary between North America and Eurasia was in eastern Hokkaido and Sakhalin. Subsequently, the boundary jumped to its present position in the Japan Sea, adding northern Honshu to the North American Plate and initiating a new zone of convergence west of northern Honshu, according to Nakamura. Kensaku Tamaki (Geological Survey of Japan, Tsukuba) showed that the deepest part of the Japan Sea is its eastern margin from Sakhalin Island to the west side of Hokkaido and northern Honshu. That margin is marked by a seismically active zone of thrust faults, one of which produced the Japan Sea earthquake of May 26, 1983 (magnitude 7.7). Nakamura suggested that the reverse fault zone is a nascent converging boundary between the subducting Eurasian Plate (Japan Sea) and the North American Plate (northern Honshu); the boundary must extend north into eastern Siberia and join the Mid-Arctic Ridge. The converging boundary extends south and becomes the Fossa Magna in central Honshu.

The Japanese scientists gave carefully documented and meticulously described examples of late Quaternary faulting. Akira Sangawa (Geological Survey of Japan, Tsukuba) described an area near Osaka in central Honshu where an east-trending right-slip fault parallel to the Median Tectonic Line changes to a north-trending thrust fault adjacent to the Nara Basin. In a poster session, Ota showed maps of a deep trench across a fault in which both sides and both ends of the trench had been mapped. The best way to visualize the geology of the trench is as a three-dimensional cut-out model. The trench is part of a project to compare thrust faults and strike-slip faults from data obtained from trench exposures. The new technique of dating most recent fault movement by electron spin resonance was described by Tanio Ito (University of Tokyo). Applied to thin films of fault gouge, the dating technique depends on the temperature of shear heating associated with faulting; he estimated it to be between 300° and 400°C.

Active Asian tectonism was the subject of several papers. Wang Su-yun (State Seismology Bureau, Beijing)

showed a stress-trajectory map of east China based on nodal-plane solutions of microearthquakes. Axes of maximum compression are almost perpendicular to the curved coastline of China; tension axes are parallel to the coast. Peter Molnar (Massachusetts Institute of Technology) and Deng Qidong (State Seismology Bureau, Beijing) calculated the average rates of deformation of much of central Asia based on source parameters of large earthquakes and surface rupture on accompanying faults since 1900. Those rates are consistent with rates predicted by plate tectonics. They indicate that the Himalayan Range is underthrusting Tibet at rates between 10 and 50 mm a year, probably less than the Minster-Jordan plate-convergence rate of India with Eurasia. D.P. Rao (Indian Institute of Remote Sensing, Dehra Dun) presented evidence of late Quaternary thrusting in the Siwalik molasse of the Himalayan foothills. Some of the faulting has the south side up, so that the fault scarps face the Himalaya.

In a lively session, Earl Hart (California Division of Mines & Geology, San Francisco) and Warwick Smith (New Zealand Geophysics Division, Wellington) described the ways in which California and New Zealand assess seismic risk. California state law requires the Division of Mines & Geology to set up regulatory zones for

faults that show evidence of Holocene activity and are well-defined surface features. However, the law does not require zoning of linear belts of high seismicity that have no surface evidence of Holocene activity such as those in the northern Coast Ranges east of the San Andreas Fault, illustrated at the meeting by Jean Olson (Victoria University, Wellington). The California law may have been inspired by seismic risk, but it evaluates ground-rupture hazard. In contrast, zoning for earthquake hazard in New Zealand is guided more extensively by historic and instrumental seismicity. Compared with California, New Zealand does not have many examples of historic fault rupture. However, the Alpine Fault is included in the region of greatest hazard even though it has neither sustained a large earthquake nor undergone surface rupture in historic time.

A selection of the 110 papers given at the meeting will be published as a bulletin of the Royal Society of New Zealand, Wellington. The Royal Society published for the meeting an introduction to recent crustal movements of New Zealand and field guides to the North and South Islands (Royal Society *Miscellaneous Series*, v. 7, 8 and 9).

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on Leg 96

Challenger drills Mississippi Fan

Glomar Challenger sailed on Sept. 29 from Fort Lauderdale on Leg 96, the last voyage of the 15-year Deep Sea Drilling Project, and docked on Nov. 8 in Mobile. The final leg studied the Mississippi Fan, one of Earth's large deep-sea fans, and the Orca and Pigmy basins, two intra-slope depressions between diapirically intruded salt masses. We relied on the Advanced Piston Corer to obtain relatively undisturbed cores with good recovery. Well logs provided a continuous sequence wherever core recovery was poor. Challenger drilled at nine sites on the Mississippi Fan and at one site in each of the basins.

The Mississippi Fan is a broad, thick

arcuate accumulation of Pleistocene shallow-water sediments extending almost 600 km from near the present Mississippi River Delta onto the Gulf of Mexico abyssal plain. Seismic data show that the fan consists of elongate sediment bodies—fan lobes—that migrate both laterally and seaward. The youngest fan lobe, late Wisconsin glacial in age, has a large, sinuous central channel that decreases in width, depth and sinuosity downtown.

In the middle fan, the youngest lobe is about 400 m thick and 150 km wide; it is strongly convex in cross section. Its most prominent feature is a central large leveed channel bounded by numerous ridges and swales,

suggesting abandoned-channel scars. The channel is 3 to 4 km wide, has a relief of 40 to 50 m and is bounded by prominent ridges or levees. The broad plain that it traverses is mostly smooth.

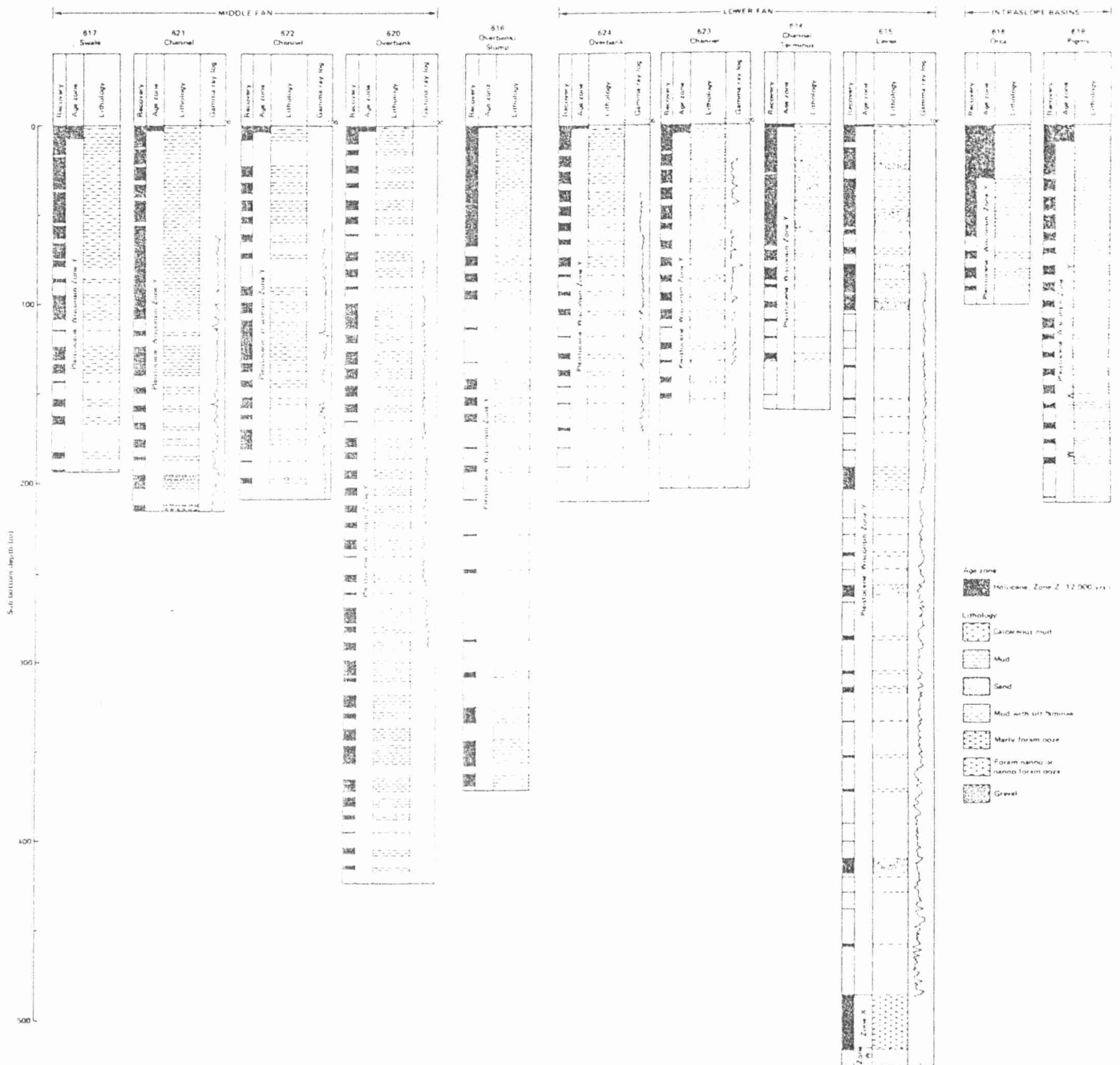
Sites 621 and 622 lie in the central channel at a water depth of about 2,500 m. Seismic data show high-amplitude discontinuous reflectors to a depth of 317 m below the channel floor. The geometry of the reflectors suggests both lateral and vertical migratory patterns. The cored channel-fill sequence shows a fining-upward trend from gravel through alternating sands, silts and thin-bedded muds into thick-bedded muds. The gamma logs show sands with sharp bases and rather abrupt tops. Incorporated fau-

nas are primarily displaced shallow-water benthic foraminifera. Accumulation rates of the channel fill were extremely high, averaging more than 11 m per 1,000 years. The nearest source of gravel is on the shelf near the head of the Mississippi Canyon, indicating a minimum transport distance of more than 220 km.

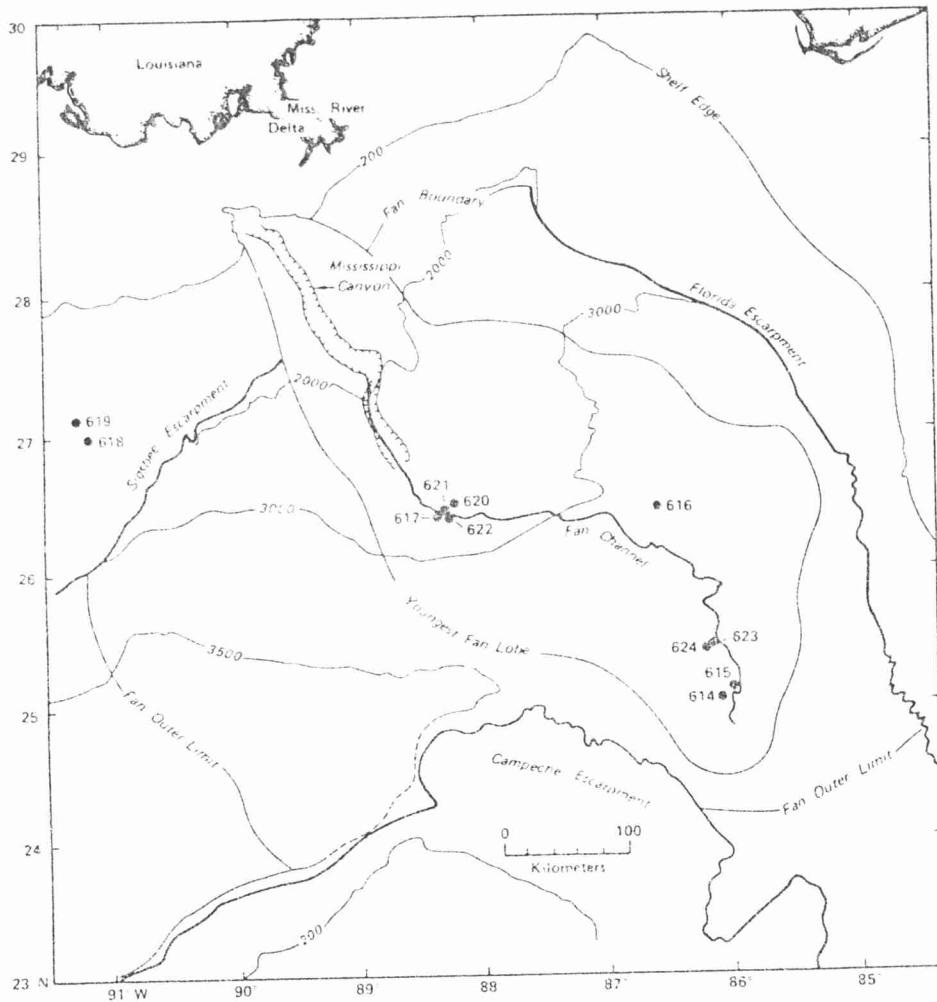
Site 617 was drilled to 191.2 m in a swale on the western side of the channel. It disclosed three units capped by a thin foraminifera-rich mud: 1) a lower coarsening-upward sequence 108 m thick composed primarily of muds with silt laminations; 2) a relatively uniform graded-silt laminated mud 38 m thick; and 3) an uppermost fining-upward mud with some silt laminae. The entire interval

is interpreted as mud or fine-grained silty turbidites forming levee and overbank deposits. Variations in grain size are a function of nearness to the channel during accumulation. Sedimentation rates ranged from 2.5 to 12 m per 1,000 years in the lower part of the deposits to 2.5 m per 1,000 years near the top.

Site 620 lies 18.3 km from the channel in overbank deposits of the youngest fan lobe. The 422.7-m hole penetrated the base of the youngest lobe at 384 m and recovered a mud unit containing abundant bathyal benthic foraminifera. The overbank sediments are mostly alternating intervals of muds, clayey muds and silts with a sparse microfauna that has been displaced



Leg 96 of the Deep Sea Drilling Project drilled nine holes in the Mississippi Fan and two in intraslope basins. These are the stratigraphic summaries of sites drilled on Challenger's last voyage. (From DSDP, Scripps Institution of Oceanography)



Site map shows locations drilled off Louisiana on Leg 96 of the Deep Sea Drilling Project. (From DSDP, Scripps Institution of Oceanography)

from shallow neritic environments. The gamma log shows that, in general, the lithologic units coarsen upward and that the silt units vary in thickness from a few centimeters to more than 5 m. According to log response, the overbank sediments are composed of 2.8% sand, 24.5% silt and 72.7% clay. The major acoustical units offlap onto the reflector that marks the base of the youngest fan lobe. The accumulation rate was 11.8 m per 1,000 years.

Site 616 is 55 km northeast of the channel in what has been termed a massive 'slump deposit' that masks the youngest fan lobe. The 371-m cored hole penetrated, from bottom to top, a lower mud unit 121 m thick; a sand-rich unit 100 m thick; a fining-upward sand, silt and mud sequence 55 m thick; and a steeply dipping silt and mud unit 95 m thick capped by a thin, marly Holocene foraminiferal ooze. The upper unit was interpreted as a mass-movement deposit, probably emplaced by late Pleistocene sliding. The lower cores penetrated fan lobes that predate the latest Pleistocene lobe. The oldest fan lobe shows a coarsening-upward sequence containing 7% net sand, while the young-

er lobe, 88 m thick, has 33.8 m net sand (38.5%). The sediments are interpreted to be the result of deposition by turbidity currents. Accumulation rates at the site were 5.6 m per 1,000 years.

The main lower fan channel narrows to less than 500 m, decreases in relief (5 to 10 m deep) and becomes less sinuous. Abandoned channels, as mapped from side-scan sonar data, suggest that channel switching is a common process.

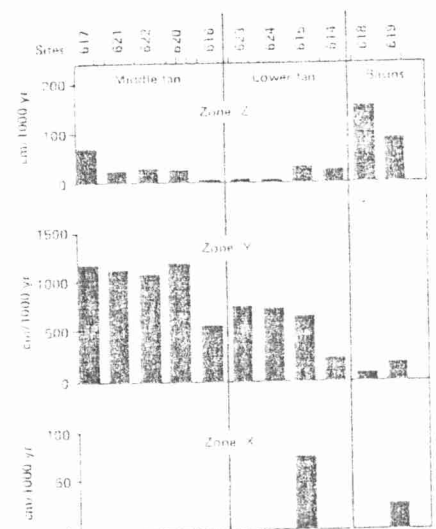
We drilled at sites 623 and 624 on the margins of the lower fan channel to evaluate the nature of the channel and overbank deposits where they cease to be confined by prominent levees. Both sites consist of alternating channel-fill and overbank deposits. The channel fills are thin (generally less than 15-m) intervals of sharp-based sands grading upward into laminated silty muds and occasionally muds. The overbank intervals are poorly defined coarsening-upward sequences of interbedded thin sands, silts, silty muds and homogeneous muds. The data suggest that, during the construction of a fan lobe, the lower fan channels occupy different positions for short periods of time,

then switch to another position rather than maintain a stable position or migrate laterally.

Site 615 was drilled to 523.2 m on the western levee of the lower fan channel into deposits of early Wisconsin glacial age. The modern fan lobe is 202 m thick; the underlying older lobe, 274 m thick. The youngest fan lobe contains a net sand thickness of 81.7 m (41.1%); the underlying fan lobe contains 183.0 m (65.1%) net sand. Both fan lobes display a coarsening-upward trend to blocky, 2- to 10-m thick graded sands and are capped by a fining-upward sequence (levee deposits). The late Wisconsin interstadial (Ericson Zone X) consists of a fining-upward carbonate sequence probably derived from the West Florida platform. Sedimentary structures indicative of deposition by debris flow occurred throughout the cores.

Challenger drilled Site 614 near the terminus of the modern lower fan channel; the hole penetrated the youngest fan lobe and extended into the older underlying lobe. The older lobe contains a coarsening-upward unit of silt and mud with thin sands that grade abruptly upward into a unit about 75 m thick consisting of blocky sands 1 to 3 m thick, separated by thin muds. Microfauna is rare, and only shallow-water displaced forms are present. Accumulation rates computed for this site are 2.1 m per 1,000 years.

Large-scale hummocky topography of the continental slope off Louisiana and east Texas results largely from salt diapirism. Small isolated depressions between the diapirs are often filled with thick continuous sequences of



Undecompressed accumulation rates of sediments drilled on DSDP Leg 96 were very high, as shown by this graph. (From DSDP, Scripps Institution of Oceanography)

Tertiary and Pleistocene sediment.

Site 618 is in the Orca Basin, which contains a hypersaline, anoxic, brine bottom layer 200 m thick. The recovered gas-disrupted clay sequence contains only displaced Pleistocene and Pliocene fauna. Fragments of ice-like gas hydrates ranging from a few millimeters to a few centimeters in diameter were finely dispersed in the sediments. Active salt diapirism appears to have been a major cause of sediment instability on the basin slopes, resulting in considerable amounts of reworked material on the basin floor. The hole bottomed in late Wisconsin glacial sediments. The Holocene sediments accumulated in an anoxic environment as indicated by the alternating dark-black and grey clays containing a sparse benthic fauna. Pore-fluid salinities decreased from about 230 ppt at the mudline to 55 ppt at 30 m; lower, the salinity remained relatively constant. The gas showed the high C1:C2 ratios (greater than 4,000) typical of biogenic origin, and it probably originated in anoxic sediments below the surface brine layer. Microorganism culturing experiments carried out onboard disclosed biogenic methane production in three cores taken from 15 to 40 m beneath the bottom.

Site 619 is in Pigmy Basin. The clay sequence recovered contains a well-preserved and rather complete Holocene and Wisconsin (Ericson Zones Z, Y, X and W) biostratigraphic section. Computed accumulation rates range

from 23.8 to 186.3 cm per 1,000 years. The top of Zone X was capped by a thin layer of volcanic ash that possibly correlates with the Y-8 ash assigned an age of 84,000 years. Most of the fill represents pelagic and hemipelagic sedimentation with only minor interruptions by localized mass-movement deposits.

The major scientific conclusions from Leg 96 drilling in the Mississippi Fan: 1) The Mississippi Fan consists of a number of elongate fan lobes, each composed of a channel-levee-overbank sequence characterized by differing lithologic and paleontologic units. 2) Middle-fan coarse sand and gravel deposits are localized within the migratory channel system. Lower fan sands spread laterally by shifting depositional lobes at channel mouths. Overbank and channel fill sediments are fine-grained. 3) Accumulation rates were extremely rapid. Late Wisconsin glacial rates ranged from 11.75 m per 1,000 years in the middle fan to 6.46 m per 1,000 years in the lower fan. Sediment deposition was primarily by density flows, resulting in mud-rich to sand- and gravel-rich turbidite deposits. 4) Bathyal benthic and planktonic microfauna are rare because of the very rapid accumulation rates; displaced shallow-water neritic faunas are more common.

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land residents. The evacuation was finished July 22, the day before an explosion that subjected all but a narrow strip along the east coast to pyroclastic flows that destroyed most homes and 700,000 coconut trees on Una Una. More than 20 large summit explosions occurred through Aug. 26, and pyroclastic flows frequently swept the island. Analyses of weather satellite images suggested that tephra from some of the larger explosions penetrated the stratosphere, but atmospheric scientists did not detect major increases in its aerosol content.

After 21 years of quiescence, Miyakejima (Japan) erupted from a flank fissure for 10 hours Oct. 3-4. Tephra rose to 10 km and fell on the entire 55-km² island (population: 4,400), 175 km south of Tokyo. Tephra thickness reached 15 cm on the southeast side of the island, and the airport was forced to close. The 4-km fissure extended just offshore, where explosions, initially submarine, built a crater extending above sea level, adding new land to the southwest coast. Lava flows fed by fountains from the upper half of the fissure buried 80% of Ako, a west-coast town, and another flow entered the sea. Ako's 1,400 residents were evacuated to the north side of the island. Ako has been destroyed or badly damaged in 4 of the 13 recorded eruptions since 1085.

Explosions from Bezymianny (Kamchatka, U.S.S.R.) began May 22, ejecting ash that reached 5 to 6 km altitude and covered a 1,500-km² area east of the volcano. Part of the lava dome was destroyed, and a pyroclastic flow advanced 4 to 5 km beyond its east base. Andesitic lava was extruded from the top of the dome. Bezymianny's first historic eruption culminated in a paroxysmal directed explosion that destroyed its summit in 1956. Lava extrusion, punctuated by numerous explosive episodes, has continued since then.

On Sicily, Etna began to erupt March 27 or 28 from an upper south-flank fissure. After some initial explosive activity, lava flowed through a single deep channel for about a kilometer, then spread to form a complex field with numerous tubes and channels. Lava quickly reached hotels, restaurants, other tourist structures and private homes. Efforts to divert the main flow, particularly with large earthen barriers (the largest was 500 m long and 150,000 m³ in volume), were partly successful. One barrier deflected several million cubic meters of lava from major tourist facilities. Construction of smaller embankments continued from May 1 through the end of the eruption, Aug. 6.

Ash clouds from a 300-m cone in-

worldwide

Volcanism reviewed for 1983

None of the explosive eruptions of 1983 were as large as those at Soufrière of St Vincent in 1979, Mount St Helens in 1980, Alaid and Pagan in 1981, and El Chichón in 1982, but calderas showed signs of reawakening in Italy, Papua New Guinea and the United States. Eruptions were reported at 45 volcanoes in 1983, about the same number as in each of the two previous years. However, no eruption-related fatalities were documented, in sharp contrast to 1982, when more than 1,000 people were killed at El Chichón. Evacuation of 7,000 people prevented major loss of life in Indonesia, and about 2,000

people were evacuated in Japan; those figures were dwarfed by the tens of thousands who fled the eruptions in 1982 of Galunggung and El Chichón.

Of the 32 volcanoes with reported explosive eruptions in 1983, activity at nearly half had continued from previous years, and about a third also produced lava flows or domes. At least 10 days of seismicity preceded the July 18 onset of a powerful explosive eruption at Una Una, a small island off Sulawesi, Indonesia. The Volcanological Survey of Indonesia recommended and government authorities ordered the evacuation of all 7,000 in-