

ington. The Nanbiancun section of Guangxi is a candidate for the Devonian-Carboniferous stratotype; and the Jingyuan section in Gansu and the Ludian section in Guizhou are candidates for the mid-Carboniferous boundary stratotype.

Several options were discussed concerning the position of the Carboniferous-Permian boundary, with emphasis on the sequences in South China and the Permian type region in the western Urals of the Soviet Union. The boundary working group was reorganized by the Subcommittee on Permian Stratigraphy. The new chairman is Wu Wangshi and the new vice chairman is B.I. Chuvashov, Institute of Geology & Geochemistry, Urals Section, Academy of Sciences, U.S.S.R. The new working group is clearly several years away from any decision on either the biostratigraphic level of the boundary or the selection of an international stratotype.

Other international groups holding sessions in Beijing were the International Commission on Paleozoic Microflora and the International Commission on Coal Petrology. Specialists working with Paleozoic miospores are developing international zonal correlations based on the detailed work that has been done in Western Europe; a working group is being established to formalize this worldwide effort. The coal petrologists proposed an international classification of solid fuel, after years of discussion on

types of coal, ranks of coalification and standardization of coal nomenclature.

Highest praise goes to the geological organizations and individual geologists in China who made possible this highly successful international meeting. Among the sponsors were the Paleontological Society of China, the Nanjing Institute of Geology & Paleontology, Academia Sinica, the Geological Society of China, the Chinese Society of Coal, the Chinese Society of Petroleum, the Chinese Association for Science & Technology, and the National Natural Science Foundation.

The next congress will be held in Buenos Aires, Argentina, in fall 1991, under the revised name International Congress of Carboniferous-Permian Stratigraphy & Geology, which was accepted by the Permanent Committee for the congress at its meeting in Beijing. This change reflects the increasing participation of geologists who are specialists in the Permian System; they first became substantially involved in 1975 at the 8th congress in Moscow. The meetings of the 12th congress in Argentina, the first to be held in the Southern Hemisphere, will emphasize the late Paleozoic geology of Gondwana and correlations with better-known sequences in the Northern Hemisphere.

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Another effect of the Himalayan orogeny is construction of the world's largest submarine fan, with sediments derived from the uplift and erosion of the Himalayas. The Bengal Fan stretches more than 2,500 km from the slope south of the Ganges-Brahmaputra Delta into the Southern Hemisphere, covering nearly 3 million square kilometers and attaining a thickness of more than 16 km in the North. The total sediment thickness in the Leg 116 area is 1.5 to 2 km.

The main objectives of Leg 116 were to unravel the history of this intraplate deformation from its effects on the overlying sediments, study distal-fan depositional processes, and develop a story of Himalayan uplift from detritus carried hundreds of kilometers down the Ganges and Brahmaputra rivers and then thousands of kilometers farther down submarine channels. 3 closely spaced drilling sites were selected about 800 km south of Sri Lanka and 200 km northwest of the main Afanasy Nitikin Seamount group. On seismic reflection records across these sites, a clear distinction is evident between the pre-deformation sequence of almost constant thickness (about 1,200 m) and the syn-deformation sequence that varies from about 600 m in the axis of the trough between blocks to less than 50 m on the upper edge of some of the blocks.

Only 1 hole was drilled previously on the Bengal Fan about 1,000 km farther north (Deep Sea Drilling Project Site 218, Leg 22), and that bottomed in turbidite silts of late Miocene age. Field studies on land have suggested that the first main phase of Himalayan uplift began with the 'hard' continent-to-continent collision in middle Miocene time. It had therefore been concluded that the onset of rapid fan growth coincided with this mountain-building episode.

The first Leg 116 site (Site 717) was drilled to 828.2 m below sea floor into the thickest syn-deformation sedimentary section between adjacent faults, and recovered a nearly continuous section dating back to 10 million years ago. The second site (Site 718) penetrated a much-reduced syn-deformation sequence (185 m thick), as well as 775 m of pre-deformation sediments, yielding a complete history of fan deposition over the past 17 million years.

At the total depth of 960 m below sea floor (Site 718), the lower Miocene sediments (about 17 million years old) were dominated by micaceous sandy silt and gray mud of turbidite origin. Clearly, fan sedimentation was well under way at this time, before the inferred middle Miocene

Ocean Drilling Program, Leg 116

Scientists explore Himalayan uplift

The drillship *JOIDES Resolution* set sail July 7 from Colombo, Sri Lanka, for a location just south of the equator. Its mission was to study geological phenomena that owe their origin to the collision of India with Eurasia 3,000 km to the north in the Himalayan Mountains. The increased resistance to shortening across the Himalayas, combined with continued sea-floor spreading at the Southeast Indian Ridge, implies that the Indian-Australian plate is under severe com-

pressive stress. The result is a broad region of intraplate deformation, stretching from the Chagos-Laccadive Ridge to the Ninetyeast Ridge and from 5°N to 10°S. In the affected region, oceanic crust and overlying sediments are deformed into east-west-trending, long-wavelength (100- to 300-km) undulations with peak-to-trough amplitudes of 1 to 3 km. On a local scale, deformation is occurring on high-angle faults, 5 to 20 km apart, forming a series of fault blocks.

uplift of the Himalayas and 2,500 km from the mouth of the Ganges. This implies that major uplift of the Himalayas might have been earlier than previously thought. Active, vigorous erosion was occurring by early Miocene time.

The gross character of sedimentation changed several times through the 17-million-year record recovered at Leg 116 drill sites. The most obvious change was from the silty turbidite sections of Miocene and Pleistocene times to the mainly mud turbidite sections separated by pelagic clays that characterize Pliocene deposition. The chief factors controlling this variation were Himalayan uplift tectonics and sea-level fluctuations.

The main phases of uplift during Miocene and late Pleistocene times would have significantly increased the supply of sediment to the delta and pro-delta areas at the head of the Bay of Bengal. These are the periods during which silty turbidites were dominant on the distal fan. However, there is also good correspondence between the more silty units and eustatic sea-level fluctuations. The abrupt change from silty turbidites of Lithologic Unit V to the mud-dominated Lithologic Unit IV coincides with a late Miocene rise in sea level. The onset of silt turbidite deposition of Lithologic Unit II coincides with

the late Pleistocene lowering of sea level. In detail, though, the many Plio-Pleistocene sea-level changes and the general high stand of middle Miocene time do not appear to be reflected in the sediment record.

Other factors that influenced sedimentation locally were tectonic movement along faults caused by intraplate deformation, and the normal patterns of fan growth, including channel migration and lobe switching.

One important feature of the sediment record observed at all 3 sites is a marked hiatus between Pliocene and late Pleistocene time. Just under 1 million years of early Pleistocene time is absent at Sites 717 and 719, and perhaps some late Pliocene time at Site 718, although the record may simply be much more condensed at this site. We are uncertain of the origin and regional extent of this hiatus. It may imply major climatic/oceanographic changes leading to increased bottom circulation in the Central Indian Ocean and the consequent non-deposition of sediments in the Leg 116 area. Another alternative explanation might be a dramatic reduction in sediment supply, perhaps caused by diversion of the main turbidity currents feeding the Nicobar Fan.

Enormous volumes of sediment are supplied to the distal portion of the fan, with sediment-accumulation rates at times exceeding 350 m per million years. The thickness of individual turbidites recovered ranges from less than 0.01 to more than 2.5 m. The mean grain size at the turbidite base ranges up to coarse silt/fine sand, and the maximum size of quartz grains deposited is coarse sand.

Several turbidite facies can be identified, which may reflect different sources. Gray micaceous silts and silt-to-mud turbidites may be derived directly from the sediment load deposited on and beyond the Ganges Delta, partly because they are the most abundant facies type and partly because of their exclusively terrigenous composition. On average, they reached the distal fan with a frequency on the order of 1 every 1,000 years, during Miocene and late Pleistocene times. Dark-gray mud turbidites, with up to 5% plant debris and common calcareous nannofossils, may have been derived from the slumping of unstable sediments on the upper slope in the northern and/or western Bay of Bengal. These turbidity flows apparently reached the distal fan with a frequency of about 1 every 10,000 years mainly during the latest Miocene and Pliocene times. Distinctive green biogenic turbidites containing shelf foraminifers and diatoms, and white silty calcareous turbidites with an upper bathyal microfossil assemblage, are interbedded with the terrigenous material in specific zones. The former may have been derived from a shelf-slope source, whereas the latter were more likely derived from local seamounts of the Afanasy Nitikin group.

Much shore-based work is needed to refine and confirm our preliminary interpretations of sediment source. For example, the thin-bedded, green silt-mud turbidites and interbedded red-brown clays that become more common toward the base of the recovered section might reflect the influence of an Indian margin source earlier in the fan history.

Drilling at all 3 sites penetrated the entire syn-deformation sequence, and the available biostratigraphic data suggest an age of about 7 million years for the onset of faulting. These movements have resulted in a significant difference in the sedimentary sections between Site 717, in the trough between faults, and Sites 718 and 719, on the flanks of 2 adjacent fault blocks.

Correlation between the 2 sites on the northern fault block shows a reduction of about 30% in the top 600 m of section from Site 717 to Site 719.

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Most (160 m) of this thinning takes place in the more slowly deposited muddy intervals (Lithologic Units III and IV), whereas the upper silty turbidites (Lithologic Unit II) are reduced by only 15 m at Site 719, and no thinning is noted in the upper part of Lithologic Unit V.

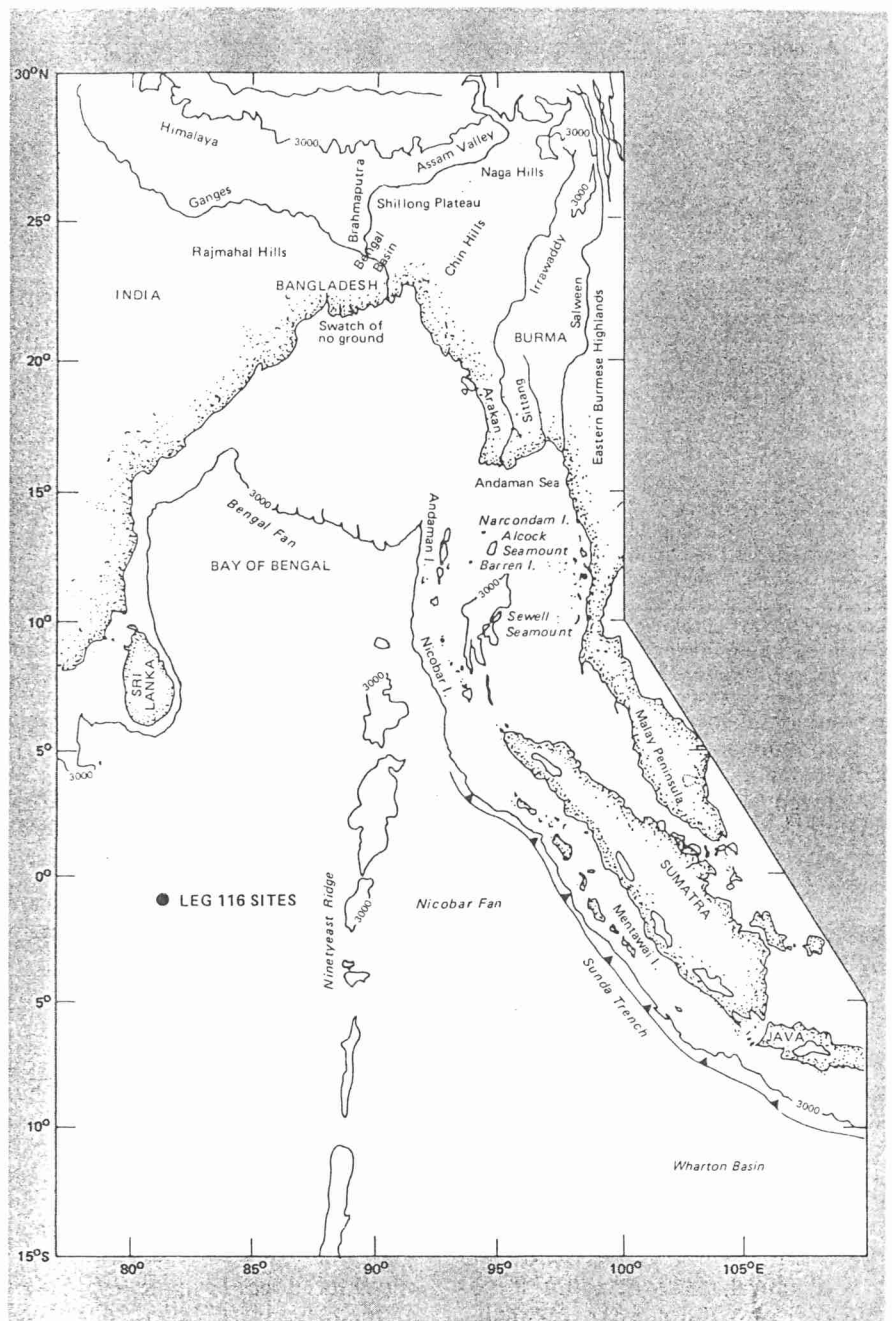
There are 3 possible causes for this dramatic reduction in section thickness between sites that are only 3 km apart on the distal fan. The first is marked thinning of individual turbidites, which can be demonstrated clearly for some beds, but does not appear adequate to account for all of the missing section. The second is non-deposition of certain beds, which also seems evident from preliminary bed-to-bed correlation between sites. The third is erosion, which appears from the seismic reflection record to have occurred at the top of Lithologic Unit III.

Apparently, motion on the block has been gradual and has been occurring at a fairly constant rate for the past 7 million years, although some evidence indicates that it began more slowly and then accelerated to about 2 million years ago. The average rate can be calculated from the amount of displacement on oceanic crust across the fault as about 50 m per million years. However, the bed-to-bed correlation now in progress, when combined with wireline-log correlation and biostratigraphic data, will allow researchers to develop more detailed history of the motion.

Heat flow in the intraplate-deformation area is generally higher than expected for oceanic crust of its age and shows considerable variation. A detailed heat-flow survey conducted as part of the pre-cruise site survey showed great variability, on the scale of a few kilometers. Site 718 was located on a local heat-flow high and yielded clear evidence of vigorous hydrothermal circulation in the form of a temperature inversion at a depth of about 100 m below sea floor.

Temperatures measured in the Pleistocene silty turbidites of Lithologic Unit II were scattered (4.2° to 11.8°C) and were actually higher than in the upper part of the underlying muddy turbidites. It appears that warm water is rising up the fault plane north of Site 718 and spreading laterally through permeable layers in the upper silty turbidites. At the same time, cooler sea water must be flowing down through permeable silt layers within the predominantly mud turbidites below (Lithologic Unit IV), which appear to crop out several kilometers to the south at the tip of the fault block.

These conclusions are supported



This map shows drill sites of Ocean Drilling Program's Leg 116. (From Ocean Drilling Program)

by geochemical studies of interstitial water that show the effects of mixing between 2 end members, one of which is bottom sea water and the other a water that has been chemically altered by interaction with basement rocks or by diagenetic processes within the sediments.

Preliminary scientific conclusions of Leg 116:

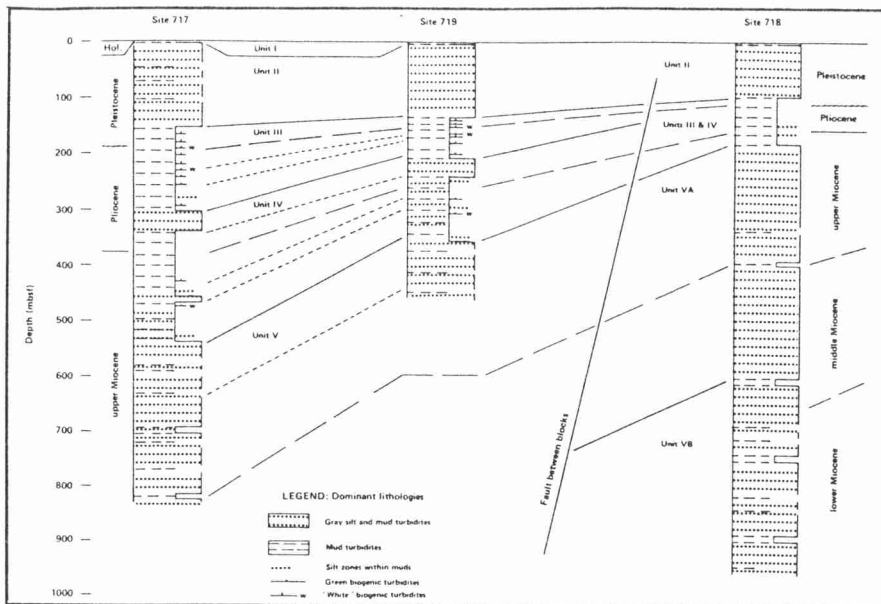
The history of the Bengal Fan goes back to at least 17 million years, which pushes back the onset of the first main phase of Himalayan uplift to early Miocene time or before. The fan is at least 1.3 km thick some 2,500 km from the Ganges delta. Both Himalayan uplift and sea-level fluctuation have markedly influenced the relative

rate of fan growth and the type of sediment deposited.

A hiatus in the sedimentary record at all 3 sites of nearly 1 million years duration is evident between Pliocene and late Pleistocene time. This hiatus may be related to a change in deep ocean circulation or in terrigenous-sediment supply during that time.

The primary source of sediments for the fan appears to be the Ganges-Brahmaputra drainage basin. However, the continental margins of the western Bay of Bengal may have contributed significantly, with a lesser contribution from local seamounts.

Intraplate deformation began to affect this part of the Central Indian Ocean about 7 million years ago. Movement along high-angle faults be-



On this chart of lithologic columns for Sites 717, 718, and 719, correlation between sites shows unit boundaries (solid lines), stratigraphic boundaries (long-dash lines), and correlation of selected marker beds (short-dash lines). (From Ocean Drilling Program)

tween blocks since that time has had a pronounced effect on local sedimentation.

A currently active hydrothermal circulation system in the upper sedimentary section is controlled by the

geometry of the deformed fault blocks.

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in Louisiana

Gas outbursts studied at domal salt mines

On June 8, 1979, at about 11:00 p.m., an outburst of methane and salt occurred at Cargill Inc.'s Belle Isle Mine near New Iberia in southern Louisiana. The methane explosion that occurred 10 minutes later left 5 miners dead. This type of gas explosion has historically plagued underground coal mines but is rare in the domal salt mining industry. This disaster prompted the U.S. Bureau of Mines to become involved in investigating the nature of methane occurrence and the factors that influence its presence in Louisiana's domal salt mines.

Hydrocarbons have long been associated with diapiric salt structures in the Gulf Coast region. The disturbed strata on the flanks of piercement domes form particularly good sites for the accumulation of oil and gas. The presence of methane in the salt dome itself is also well documented. In the Middle Ages, Polish salt miners

whose job it was to ignite accumulated methane were called 'penitants' because of their practice of crawling through the workings to avoid causing turbulent air currents.

All except 1 of the 5 famous island salt mines in southern Louisiana have reported outbursts during face production, and outbursts and gas emissions during undercutting or drilling operations. Surpassed in severity only by inundation of fresh water into the mine, explosions and fires caused by methane emission are a very serious hazard in domal salt mines.

Outbursts are by far the most significant source of methane in the mine atmosphere. They can be defined as the rapid expulsion of rock salt and methane into the mine opening. In almost every case, outbursts occur only when the stressed zone is intercepted by production blasting. After a face is loaded with explosives and blasted between shifts, a fire boss

inspects the mine. If an outburst has occurred it usually appears as a conical cavity representing an overbreakage of salt at the roof and rib junction. The amount of salt ejected from the outburst is related to the volume of the cavity. Also, salt crystals from the outburst cavity are smaller and more uniform in size than those produced by the blast itself.

Outbursts can occur with explosive force. At one mine an outburst emitted more than 600,000 cubic feet of methane and more than 15,000 tons of salt into the entry. Their shape is best characterized as a conical spiral that almost always propagates up into the roof and rib but can exhibit many variations. Outburst cavities can range in size from 1 to more than 100 ft in diameter; their height, measured by helium-filled balloons, has reached as high as 280 ft, and some may extend higher.

Unlike conventional rockbursts, which result from excessively high ground pressures, the outbursts in Louisiana mines are at least partly methane-driven. The outburst at Belle Isle expelled salt and methane, causing an overpressure situation. In another salt mine in the area a recent outburst also caused a measurable overpressure situation. High gas pressures have been measured in test drill holes, and there are many examples of pressurized gas being expelled from face and floor production drill holes.

Because of the rheological nature of salt it is rare to find natural openings or even fractures in salt domes. Gases occur rarely in cavities but are entrained in salt crystals or on the interface between crystals. Rock salt, known as 'crackle salt' or 'popcorn salt,' is common in ejected piles of outbursts. The salt, when crushed underfoot, makes a crackling noise from the release of highly pressured gas. Intragranular bubbles (millimeters in diameter) containing methane and brine are easily observed.

Gas bubbles, under an estimated 500 to 1,000 atmospheres of in situ pressure, can be contained in isolated salt crystals at atmospheric pressure after blowouts. That fact attests to the impermeability and containment properties of normal salt crystals. Normal rock salt has negligible permeability and porosity. For example, at another mine work was proceeding west along an entry when outbursts occurred. Work was halted in that entry and continued elsewhere in the mine. After 10 years, mining was resumed and outbursts occurred immediately in the first face blast, showing that gas pressure was not significantly relieved in 10 years.