needs during the "energy crisis." The extent to which the SO_2 concentration may ultimately rise is a matter for serious concern, for increased concentrations may promote still more serious and widespread acid rain with all that this outcome implies for the structure and function of both natural and man-manipulated ecosystems.

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12. There is no record of *p*H measurements, HCO_3^- determinations, or methyl orange reactions for the precipitation samples collected at Ithaca, New York, during 1915–1952 [B. D. Wilson, *Soil Sci.* **11**, 101 (1921); *J. Am. Soc. Agron.* **13**, 226 (1921); *ibid.* **15**, 453 (1923); *ibid.* **18**, 1108 (1926); E. W. Leland, *Agron. J.* **44** (No. 4), 172 (1952)].
13. Data for Geneva and Ithaca are derived from various published sources; procedures for collection and analysis of samples have been evaluated in relation to observed trends in precipitation chemistry (*5*). Wilson (*12*) believed that, prior to 1923, the area adjacent to the precipitation collector at Ithaca was relatively free of smoke. However, in 1923 a large heating plant (Cornell University) was constructed within 1.6 km from the collection area and the sulfur content of precipitation (annual averages) was thereafter appreciably increased, at times more than doubled. At Geneva a branch railroad passed within 183 to 214 m of the precipitation collector and a coal-burning flour mill was also nearby (*11*). Various events, including the economic depression of the 1930's, the World War II industrial effort in the early 1940's, and the coal miners' strike in 1945, have undoubtedly affected the amounts of nitrogen and sulfur in precipitation.
14. An alkaline response to methyl orange indicator was observed in every precipitation sample collected in Tennessee during 1919–1921 in spite of high concentrations of sulfur in the samples [W. H. MacIntire and J. B. Young, *Soil Sci.* **15**, 205 (1923)]. This was attributed to excess amounts of "lime" and other neutralizing bases in soot and fine dust found in precipitation samples. Moreover, the total amount of sulfur precipitated was about five times greater than the amount in water-soluble forms and was directly related to the amount of solid soot falling directly or with precipitation.
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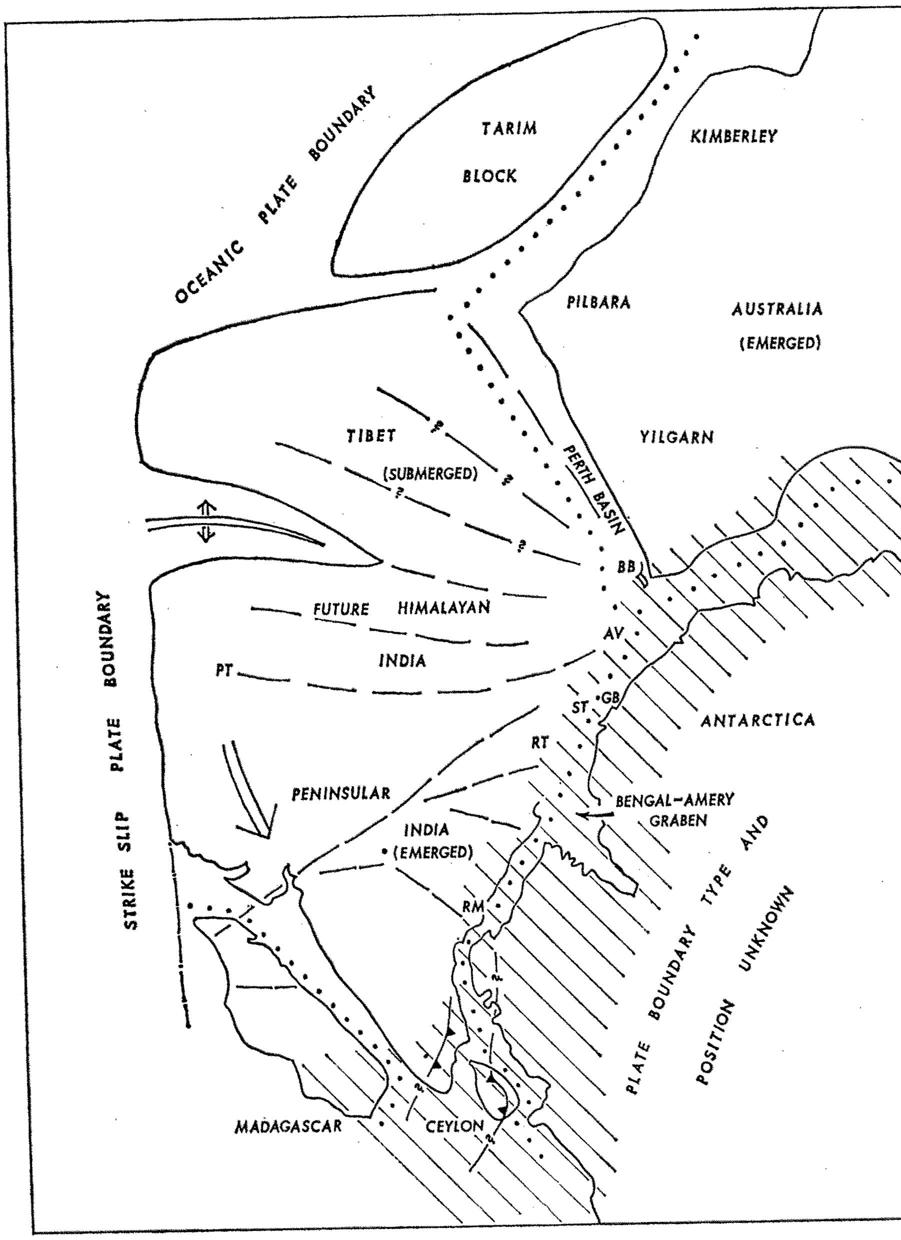
A Greater Gondwanaland

Abstract. *Gondwanaland at its maximum extent included Tibet, the Tarim Basin block, and parts of northern China. Tibet lay between India and Western Australia as submerged continental crust. The Himalayas are of intracontinental origin. The Tien Shan lie along the former oceanic boundary of Gondwanaland.*

In Gondwanaland reassemblies, two important problems are the present location of the continental crust which lay between Australia and India (*1*) and the present relation of India to the rest of Asia. The Himalayas are believed (*2*) by some to be the product of continental collision preceded by subduction of Tethyan oceanic crust. Critics of continental drift (*3*) have stressed that there are enigmatic relationships between India and the rest of Asia which are inconsistent with such collision.

I suggest that the two problems are closely related. Gondwanaland was much larger than generally believed; it included Tibet and the Tarim Basin block, the Himalayas having formed intracontinentally. Evidence against collision comes from the anomalous position of the Indus Suture Line (*4*) which, if it is the relic of oceanic subduction preceding collision, lies on the wrong side of the Himalayas. I have suggested (*5*) that the line is a relic of a Permojurassic oceanic opening to the mantle in an Indo-Tibetan area of continental crust associated with Antarctica and Australia. The opening was by counterclockwise rotation of the Indian part, relative to the rest about a pole near southwest Australia (Fig. 1). The movement was reversed during the breakaway of Indo-Tibet from Australo-Antarctica at the end of the Jurassic, and the opening then closed. The Himalayas, essentially a later product as an orogen (and a much later product in respect of their present height) (*6*) developed along fractures that had formed parallel to the Indus Suture Line opening and in which the Himalayan



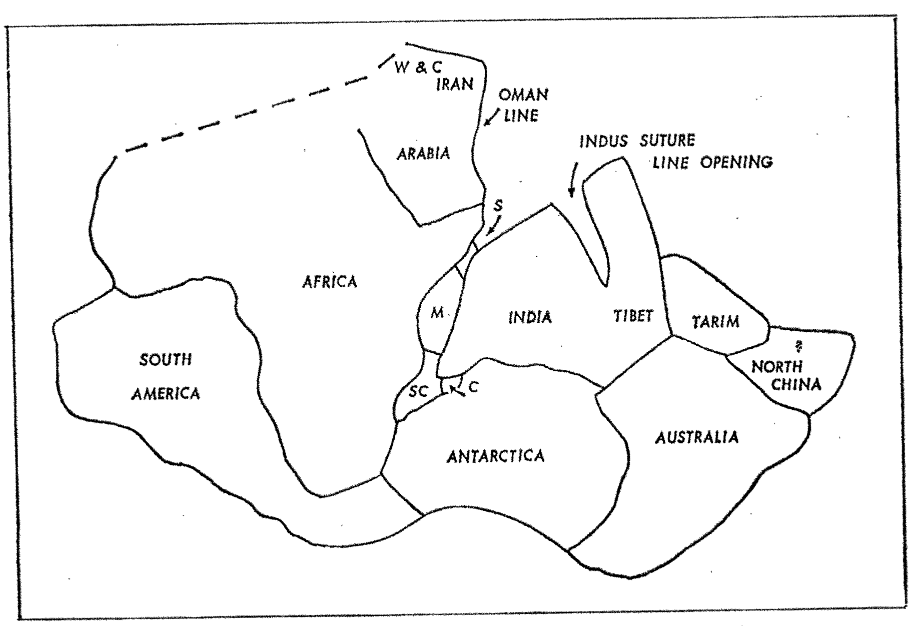


Fig. 1 (top). Part of Gondwanaland during the Permian–Late Jurassic, showing diagrammatically the opening to the mantle and the development of oceanic crust in the area now closed, subduced, and represented by the Indus Suture Line. Present-day coastal outlines are used to assist recognition, but the western limit of Australia is the Darling Fault system. The opening developed by counterclockwise rotation of the Indian part relative to the Tibetan and Antarctican parts about a pole near southwestern Australia. Associated rifts developed which, in an emerged India, allowed preservation of largely terrestrial Gondwana sediments. The rotation led to thrusting and some strike-slip in the Ceylon–south Indian part of the Late Precambrian–Early Palaeozoic zone of mobility (hatched) along which crustal separation between India (with Ceylon) and Australo-Antarctica took place finally in the late Jurassic–Cretaceous along dotted lines. Periodic volcanism occurred during this whole time at localities marked: *AV*, Abor Volcanics of Assam (Gondwana); *BB*, Bunbury Basalt of Western Australia (mid-Cretaceous); *GB*, Gaussberg, Antarctica (age unknown); *RM*, Rajahmundry Traps of Godavari graben (?Jurassic? Cretaceous); *RT*, Rajmahal Traps of West Bengal–Bihar (mid-Cretaceous); *PT*, Panjal Traps of Kashmir (Permian-Trias); *ST*, Sylhet Traps of Bangladesh (pre-Upper Cretaceous). The closing up of the oceanic zone of the Indus Suture Line, started by clockwise rotation at the time crustal separation took place between the Indo-Tibetan-Tarim part of the plate and Australo-Antarctica, although the Tarim Block may have moved rather earlier. Strike-slip took place between the plate as a whole and areas to the west, and perhaps periodically between India and Madagascar before final separation of that fragment in the Cretaceous, when extensive volcanism occurred along the fracture and spread over much of India. The Bengal-Amery graben probably developed during the Jurassic when widespread volcanic effusion affected Bengal. Fig. 2 (bottom). Gondwanaland at its maximum extent. *C*, Ceylon; *M*, Madagascar; *S*, Seychelles; *SC*, South Indian Ocean submerged continental crust.

Gondwana rocks are now seen to be preserved. These fractures were those most easily affected by stresses consequent upon vigorous sea-floor spreading relatively late in the history of the Indian Ocean when no further significant movement of India toward Asia could take place. This intracontinental orogenic uplift was facilitated (i) by the presence of a massive Phanerozoic succession lying on the Tibetan but not the Indian part and (ii) by the thick salt deposits at its base.

Association of Tibet with Australia explains the extraordinary distribution of the cladoceran *Daphniopsis* (*7*), recorded only in Kerguelen, Antarctica, Australia, Tibet, and Inner Mongolia. Search for a major plate boundary north of Tibet suggests the Tien Shan, a mountain system with a Phanerozoic history of great mobility and some peculiar features, rather than the Kun Lun–Astin Tagh which separate Tibet from the Tarim Basin. In the Kuruk Tagh in the eastern part of that basin, Norin (*8*) compared the tillite-bearing sequence, which would now be regarded as Precambrian-Cambrian, with that of the Adelaidean of the type sequence in South Australia. Today a more appropriate comparison would be with the Kimberley Basin and northern Western Australia, which on the suggested reassembly would be close.

The distribution of *Lystrosaurus* is in agreement with this hypothesis. Not only is it known in the Southern Hemisphere and India but it has been found in the Tien Shan and the Turfan Basin of Sinkiang (*9*). As related fossil reptilia occur in Shansi, it is probable that large areas of northern and northeastern China formed part of Gondwanaland (*10*). The suggested reassembly is shown in Fig. 2.

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11. I thank colleagues in Australia and elsewhere, too numerous to name individually, for help and critical comment.

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Methane Formation in Living Trees: A Microbial Origin

Abstract. *Visibly healthy hardwood trees located on poorly drained soils contained high pressures of methane. Heartwood from these trees was water-soaked, neutral to alkaline in* pH, *fetid in odor, and infested with a diverse population of obligately anaerobic bacteria. The bacterium responsible for methane formation in trees was isolated and characterized as a member of the genus* Methanobacterium.

Methane has occasionally been either reported or inferred to be part of the composition of flammable gases that are sometimes trapped within the trunks of living trees (*1*). However, the factors responsible for the formation of methane in trees have remained a mystery. We report here a microbial origin for methane found in living trees.

Bushong (*1*) reported the first analysis of gases drawn from a tree and demonstrated the presence of flammable gas in a large cottonwood tree. During the course of microbial studies with forest trees we have observed high pressure gas release from newly made increment borer holes. The gas could usually be ignited producing a blue flame (Fig. 1). The wood from these trees was often so soaked with water that a stream of fetid liquid was ejected along with the gas to distances of 15 to 46 cm, thereby extinguishing the flame. Our field observations, in addition to reports by other investigators (*1, 2*), indicate that high gas pressures do not occur in most trees and may be a condition not associated with normal growth. This study was initiated to determine the nature of high gas pressures in trees.

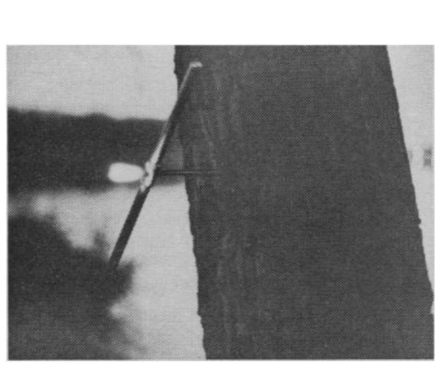

Fig. 1. Ignited methane gas emanating from a hollow increment borer bit drilled 20 cm into a cottonwood tree located on the shore of Lake Wingra, Wisconsin. Photograph is from a time exposure taken at night.

Visibly healthy trees with trunk diameters ranging from 50 to 90 cm (*3*) were selected at various locations in Wisconsin. Trees sampled included the following four species of hardwoods: American elm, *Ulmus americana* L.; black willow, *Salix nigra* Marsh.; white poplar, *Populus alba* L.; and eastern cottonwood, *P. deltoides* Bartr. An increment borer was used to sample tree trunks approximately 1 m above ground level. At intermittent distances inward boring was halted, a wood increment core was removed, and a rubber septum was immediately inserted into the borer orifice. Gas volumes twice the borer volume were first removed with a syringe, and then gas samples were collected for later analysis in a gas chromatograph equipped with a thermal conductivity detector. Methane was always a component of trunk gases that were under high pressure and was detected only in gas samples from cottonwood, elm, and willow trees that contained wetwood, an abnormal type of heartwood (*4*).

Wetwood cores removed from methane-positive trees were neutral to slightly alkaline (*p*H 6.8 to 7.8) and possessed a characteristic volatile fatty