Understanding mountain-building to earthquake prediction — the Wadia Institute of Himalayan Geology

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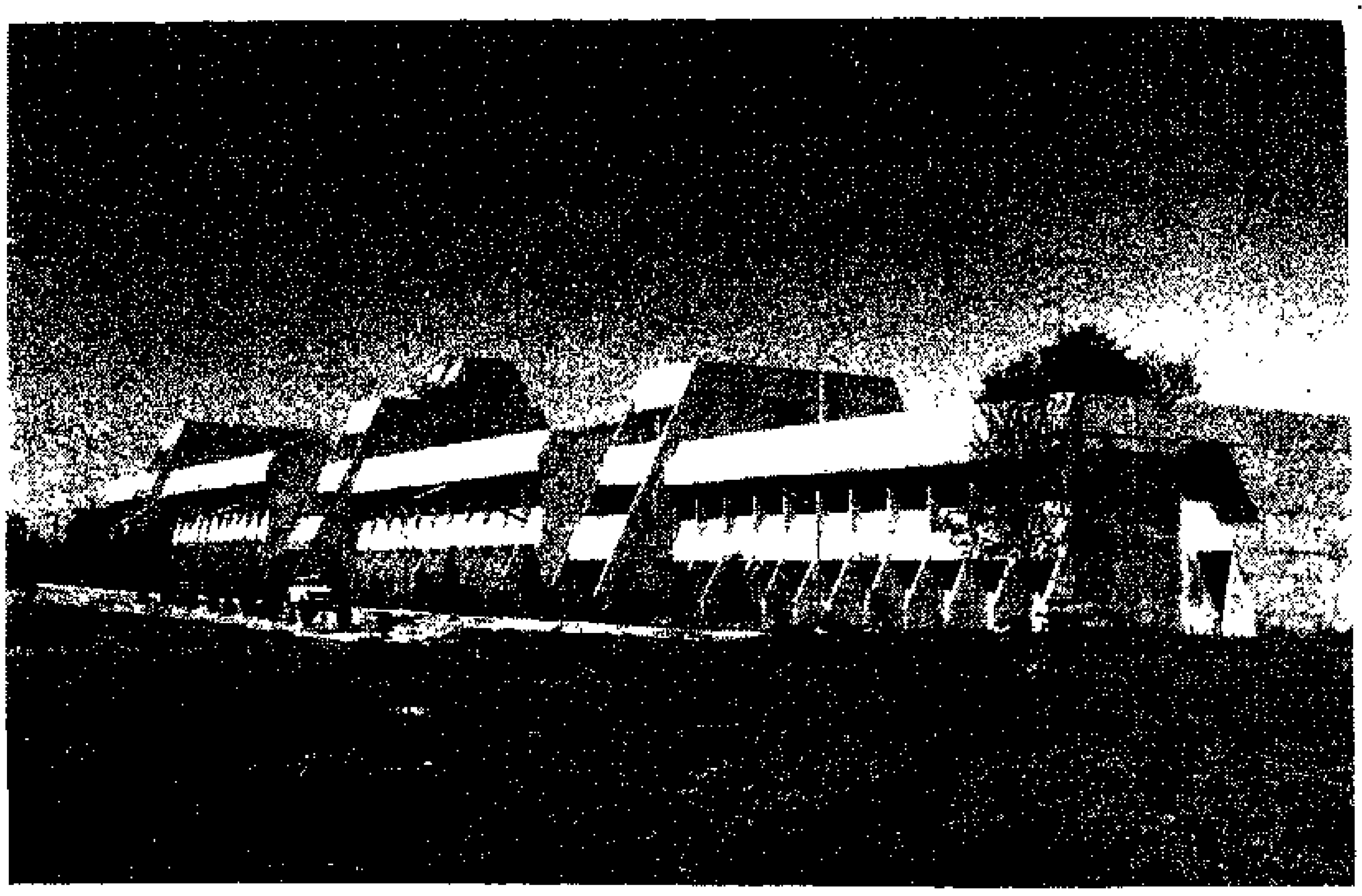
It was principally through the efforts of D. N. Wadia, FRS, National Professor, that the Institute of Himalayan Geology was established in 1968 as a registered autonomous body under the Ministry of Education, Government of India. The institute started functioning in two small rooms of the Botany Department of Delhi University, with the Head of the Geology Department acting also as its honorary director. In 1976 a full-time director was appointed and the institute was shifted from Delhi to Dehra Dun. By that time the institute had come under the Department of Science and Technology. A 15-year organizational and developmental plan projecting the institute's organizational structure and laboratory infrastructure and research activities, and defining both long-term and short-term perspective was formulated. The institute has since been able to build up a capable scientific cadre and erect basic laboratory infrastructure, and has grown into a full-fledged research institution.

Organizational structure, laboratory facilities

The research activities of the institute are organized around four major research groups: (i) structure-tectonics and seismotectonics, (ii) igneous petrology and geochemistry, (iii) sedimentology and biostratigraphy, and (iv) geomorphology and environmental geology. Two more research groups proposed for the future are geophysics and glaciology groups. The institute now has a team of fifty motivated scientists specializing in these major areas of research.

The main laboratory facilities include: X-ray fluorescence spectrometer (energy-dispersive) for major and trace element analysis of rocks; atomic absorption spectrometer and inductively coupled plasma for major, trace and rare earth geochemistry: X-ray diffractometer for rapid identification of different phases of minerals; scanning electron microscope for studying the surface morphology of microfossils, mineral grains and ore-minerals; simultaneous thermal analyser, infrared spectrometer and cathode luminescence for grain size, mechanical analysis and petrography of sedimentary rocks and for measuring temperature, pressure, salinity, density and composition of fluid inclusions entrapped in minerals. In addition to these laboratory facilities, an experimental petrology laboratory having capability up to 3 kb and temperature up to 350°C has been developed to study phase equilibria, mineral stabilities and synthesis of minerals. A fission-track dating laboratory has also been organized for studying the cooling and uplift history of the Himalaya.

The institute's library has over 6000 books on various aspects of the earth sciences and, specifically, on topics related to mountain-building processes. It has also the personal library of D. N. Wadia, which contains some rare manuscripts and old literature on the Himalaya. A museum, which depicts the geological evolution and different aspects of Himalayan geology, has also been organized.

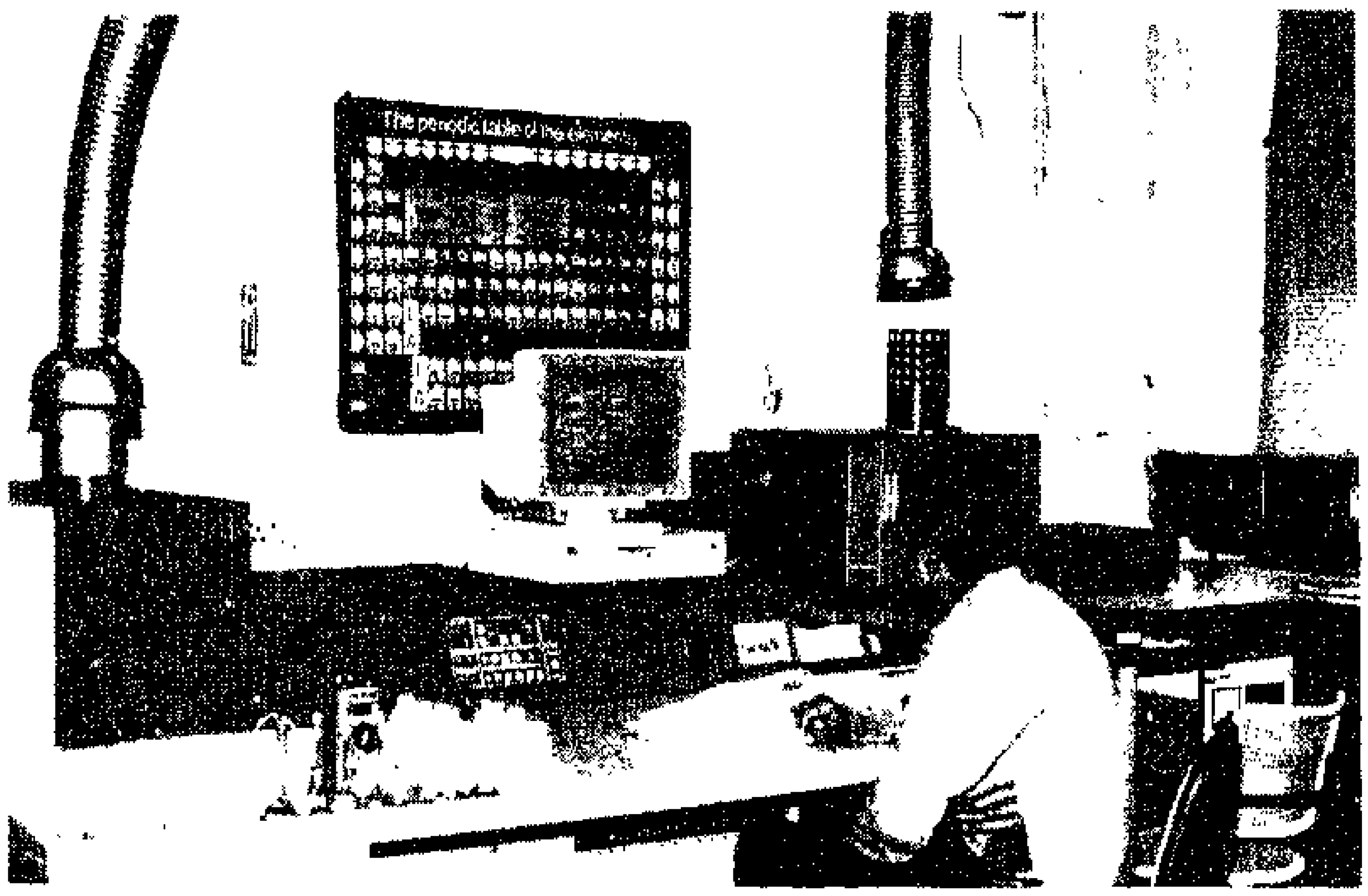

The institute's main building.

Early work—Arunachal and Kumaun Greater Himalaya

During the institute's first decade, research investigations were largely field-oriented studies. Initially the institute carried out work in the Arunachal Himalaya and Greater and Tibetan Himalaya of Kumaun.

Arunachal Pradesh in the eastern Himalaya had remained, geologically speaking, *terra incognita* owing to its very poor accessibility. Several expeditions of the institute worked out the regional geology and structural framework of the Arunachal Himalaya. A tectonostratigraphic map of this part of the eastern Himalaya was prepared.

Except for the early accounts of the reconnaissance survey in 1936–1939 by the Swiss geologists Heim and Gansser, there was general lack of geological knowledge about the Higher and Tethys Himalayan regions. Five expeditions were sent to do high-altitude geology in the region. The expeditions brought a wealth of geological data and a good collection of fossils and rock samples. A geological map of the area was prepared, cross-sections showing major structures were drawn, and a stratigraphic column of the Tethys Himalaya sequence was constructed. Based on fossil assemblages, a marine sedimentary



Inductively coupled plasma for major and trace element and rare-earth geochemistry.

sequence of approximately 6 km thickness of the Tethys Himalaya was dated to range in age from the Ordovician (450 million years ago) to the Triassic (220 million years ago). It was discovered that the Tethys Himalaya sequence does not represent sedimentation in the classical concept of 'geosyncline'. A monograph on the geology of this region of the Himalaya has been published.

The crystalline slab of the Higher Himalaya that underlies the Tethys sequence was mapped. Its deformation and metamorphic history and radiometric dating indicated that the 8–10-km-thick slab of crystallines (1800–2000 million years old), at present occupying the Great Himalayan range, was buried deep under a cover of 4–5-km-thick sedimentary sequence. The southern margin of this great slab is demarcated by a major shear zone called the Main Central Thrust, which brings the slab to override the Lesser Himalaya sediments with a southward movement of up to 60 km.

Kumaun Lesser Himalayan geology, Lesser Himalayan stratigraphy

The geology of the Kumaun Lesser Himalaya region had been studied and described by many geologists. This had led to a multiplicity in stratigraphic nomenclature for the region, and a variety of interpretations, even a geological map of the entire area was not available. WIHG's studies established the stratigraphy and structure of the Kumaun Lesser Himalaya and standardized stratigraphic nomenclature. This study forms a significant contribution.

A significant breakthrough in Lesser Himalayan stratigraphy was made with the discovery of Cambrian conodont microfossils from the phosphorite horizon in the Krol belt of the Mussoorie hills. The stratigraphy of the Lesser Himalaya sequence had always been problematic owing to its unfossiliferous nature. Earlier interpretations based on lithological correlation advocated an age ranging from the Late Precambrian to the Cretaceous and Lower Eocene. The discovery of conodonts, and subsequent reports of shelly fauna, brachiopods and trilobites by other workers necessitated a revision of the stratigraphy of the Lesser Himalaya. It has now been established that the Lesser Himalaya sequence is largely a Late Precambrian/Cambrian sequence with a major stratigraphic gap and overlain by Upper Cretaceous/Lower Eocene marine transgression beds.

The Indus Suture

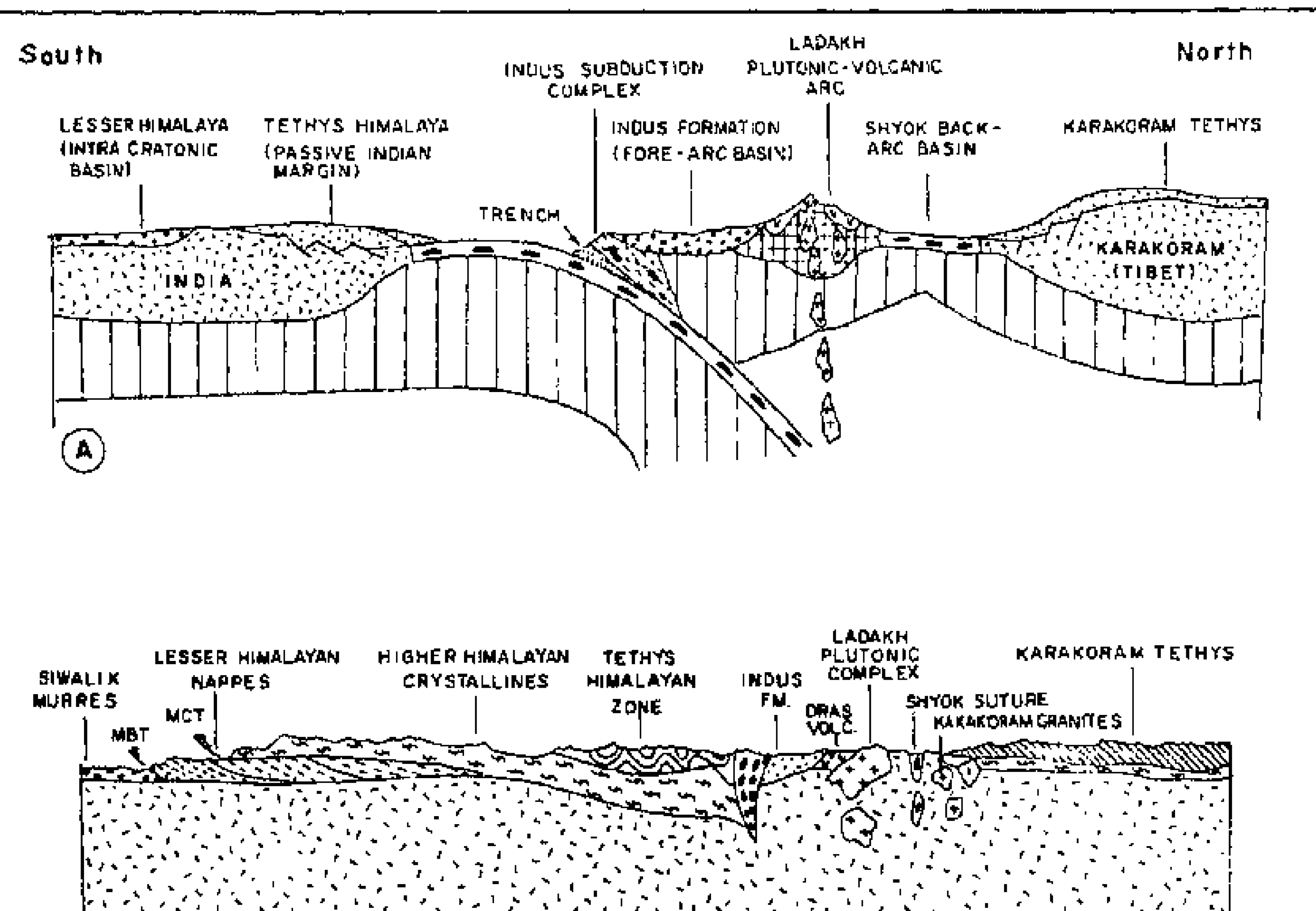
In plate-tectonic interpretation a suture zone is considered as representing the boundary between two separate continental plates. It is also believed that vast oceanic areas were consumed and closed along suture zones. North of the Great Himalayan Range and south of southern Tibet, a suture zone called the Indus Tsangpo suture was demarcated along the entire length (1500 km) of the Himalaya. In order to study the geological characteristics and tectonic evolution of this suture zone, the Ladakh region in Trans-Himalaya was selected for study. Geological mapping, and petrological, geochemical, sedimentological and palaeontological investigations were carried out. Remote and crucial areas of the western and eastern suture zones, Shyok and Karakoram regions were mapped. Based on the analyses of petrotectonic assemblages, petrology and geochemistry, an ophiolite sequence at Nidar representing a dismembered fragment of the Mesozoic ocean floor, a volcanic arc at Dras, plutonic arc of Ladakh range, back-arc basin of Shyok, and fore-arc basin of the Indus have

Camping for geological field work at 5000 metres in Zanskar, Ladakh.

been recognized. Discovery of blue schists, which suggests high-pressure and low-temperature metamorphism, ophiolitic mélanges and trench sediments indicate a palaeosubduction zone.

Plate tectonics

Application of the plate-tectonic model to the geodynamic evolution of the Himalaya was the main thrust of research. The northwestern Himalaya was selected for study, for it exposes the northern margin of the Indian Plate, the Karakoram block of the Eurasian Plate and the suture between these two plates. In the plate-tectonic model it was postulated that the Himalayan mountain system originated as the result of collision between the Indian and the Eurasian plates. This generalized model has been elaborated and palaeotectonic events reconstructed. The Neotethys lying between India and Tibet has been shown to have closed owing to northward movement of India, resulting in the consumption (subduction) of the Tethyan ocean under the Tibet block. A volcanic–plutonic arc, an ophiolite slab, ophiolitic mélanges and blue schist metamorphic belt representing the tectonic signatures have been identified, unfolding the closing history of the Tethys Ocean. The disappearance of marine environment in sedimentation took place in the Middle Eocene (50 million years ago). This event coincides with the timing of collision between the India and Tibet blocks, and also corresponds with the slowing down of the rate of northward movement of the Indian Plate. Collision of the continental blocks and the continued northward convergence of India produced crustal shortening, thickening of the crust, and slicing of the crust into slabs. The crustal slabs were stacked one upon another along major supercrustal thrusts, i.e. the Main Central Thrust, the Main Boundary Thrust and the Himalayan Frontal Thrust and were finally uplifted to form the Himalaya. The Indian continent is still converging northward at the slow rate of a few cm per year and the Himalaya is rising. The collision process operating at the crustal level produces brittle to brittle-ductile failures that trigger earthquakes, making the entire Himalyan belt seismically active.



Cartoon showing plate-tectonic evolution of Himalaya. **A**, About a hundred million years ago India started moving northward, closing the Tethys ocean gap. Subduction (consumption) of the Tethys Ocean under the Karakoram (Tibet) block produced plutonic-volcanic arc, fore-arc and back-arc basins and subduction complex. **B**, The final closure of the Tethys Ocean led to the collision of two continental blocks as the lighter continental crust of India could not subduct underneath the Tibet block. The collision tectonics produced crustal shortening and generated metamorphism and plutonism at greater depth. Development of major thrusts, nappes and folds accommodated crustal shortening. Continued northward convergence of India against Tibet reactivated the old structural features and creates new failures in rocks, making the Himalaya a seismically active mountain belt.

Vertebrate fauna from the Siwaliks

The Cainozoic sedimentary belt of the outer Himalaya has yielded a rich collection of vertebrates, microvertebrates and foraminifera. The vertebrate fauna, including *Hipparion* from the Lower Siwalik, indicates an age of 10 million years on the basis of magnetostratigraphy. A vast fluvial system comparable to that of the present Kosi river has been recognized. A rich mammalian collection of artiodactyls and rodents of the Upper Oligocene has been collected from the Kargil intermontane basin in Ladakh.

Future studies

WIHG's research programmes are oriented towards the above scenario. Presently the main thrust is directed towards understanding the geodynamic evolution of the Himalaya on the basis of studies in deformation, geochemistry, sedimentation, geomorphology and palaeontology. Future basic research programmes will give greater focus on processes involved in geodynamic evolution, dating of different tectonic episodes, palaeoclimate, estimation of uplift and erosion rates, quantitative estimation of the convergence rate of the Indian Plate, and magnitude of crustal shortening and neotectonic movements. Earthquake prediction, subsurface crustal structure of the Himalaya, landslides and slope stability, and glaciological and hydrological studies have been identified as the other important research programmes.

Geophysical coverage of the Himalaya is poor. The density of the seismic monitoring network is inadequate for an in-depth study of seismicity in the region. Wide-angle seismic reflection profiling to study the crustal structure has to be undertaken. A heat-flow profile across the Himalaya, together with a magneto-telluric study across the profile, is necessary for a better understanding of the structural evolution of the Himalaya.

Constraints

One of the prime requisites for building an institution of high standing is to have men with excellence. The present position in geoscience in recruiting good scientists is not very happy, for the best talents opt for Oil and Natural Gas Commission (ONGC), Geological Survey of India (GSI) and university teaching jobs. The rest go for PhD in the universities, and these very students look for openings in research institutions. A majority of them have poor background in mathematics and instrumentation.

Advancement in geoscience research is partly dependent on new developments in analytical techniques and instrumentation. It takes time to develop applications of techniques and knowledge from physical sciences to the study of solid-earth materials in geoscience. Capability-building is essential to orient instruments and techniques to the analysis of geological samples. The running, maintenance and standardization of instruments require the building-up of a trained and skilled manpower.

Other activities

The institute is actively participating in three major national-level projects sponsored by the Department of Science and Technology of the Government of India. These projects are: (i) Natural Resources Data Management System (NRDMS), (ii) Seismicity and Seismotectonics of the Himalayan region (SSTH), and (iii) Glaciology. Under NRDMS, a district-level data base of the Pauri district in Garhwal region of Uttar Pradesh has been established at the district headquarters Pauri-Garhwal. A computerized data base containing information on twelve parameters, including geology, land use, landslides, slope stability, flora, wildlife and water resources, as well as on some social parameters like population, income, etc. has been established at this centre. The data base centre runs under the administrative control of the District Magistrate, who finds the data base centre very useful in district-level planning. Under SSTH, two permanent observatories and six mobile observatories have been established in Himachal and Garhwal. Three glaciology expeditions, with members from eight organizations, have been organized to study the Chhota Shigri glacier in Himachal Pradesh.

The institute's scientists have provided consultancy services on a limited scale for specialized jobs such as geotechnical feasibility of hydroelectric projects, site selection for bridges, transmission towers and deep tubewells, road alignments, and control of landslides. They are also carrying out microseismic investigations for the Tehri Dam project. Besides, sample analyses for major and trace elements, thermal analyses, and X-ray diffraction and scanning electron microscopy services have been regularly provided to research and service organizations and universities.

WIHG organizes regional training courses in structural geology, sponsored by UNESCO, for participants from Afghanistan, Bangladesh, Bhutan, Burma, China, India, Iran, Mongolia, Nepal, Pakistan, Sri Lanka and Tanzania.

Importance of Himalayan studies, unresolved questions, resources

The Himalaya is very important for us because of its geological and geographical situation and because it has a direct bearing on the well-being of millions of people living in the northern and eastern states of India. There are three main aspects of the Himalaya that need better understanding and appreciation. These are: the geological and geophysical processes in mountain-building, natural resources, and environment.

The Himalayan mountain chain occupies a unique geological setting on our globe. To its south lies the Peninsular Indian Shield, which has the normal crustal thickness of 35 km, and to its north lies the highest plateau of Tibet, which has crustal thickness of 70 km. The Himalaya, lying in between, is considered to be a type-example of continent–continent collision orogenic belt.

Several questions relating to the geological evolution of the mountain range remain unanswered. For example: What is a precise estimate of the width of the Tethys Ocean? What were the crustal processes involved in the closure of the Tethys Ocean? What were the palaeogeographic patterns in the geological past in the Tibet-Karakoram, Pamir, Afghan and Iran blocks and the Eurasian landmass? What is the extent of crustal shortening and what are the processes responsible for crustal shortening in the Himalaya? What is the nature of seismicity, and the level of prediction of major earthquakes in the Himalayan region? What were the causes for the uplift? What palaeoclimatic changes have taken place in the past 4 million years? There are a host of other fundamental geoscientific problems requiring an answer. The Himalaya is an excellent natural laboratory, exposing through its well-dissected valleys and uplifted mountains the different rock formations and structures for study.

Estimates made on the basis of existing knowledge indicate that the Himalaya is not rich in mineral resources. Most of the reported economic minerals like polymetallic sulphides, chromite, antimony and tungsten constitute small-volume deposits; and the poor accessibility of the terrain makes these deposits economically not viable. Only the large-volume deposits, like limestone, magnesite and phosphorite, are being mined at present. The Himalayan rivers provide the biggest resource for generating hydroelectric power. They are perennial, being fed by glaciers, and contain a large volume of water. They originate at great heights (5000 meters) and descend to the alluvial plains of the Ganga and the Brahmaputra. These two features of Himalayan rivers, viz. the large volume of perennial water and the extreme altitude variation along their course, provide a vast potential for generating hydroelectric power.

It will not be incorrect to say that the Himalayan environment has become fragile. The degradation in environment has taken place primarily owing to removal of forest cover and pressure of population on the land. Soil erosion and reduced stability of slopes are serious environmental problems. Earthquakes, landslides and avalanches are major geological hazards in the Himalayan region.

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