Main morpho-structural elements in Bolivia from west to east are the following.

1. The Cordillera Occidental which exposes Tertiary and younger extrusives.
2. The Altiplano depression with thick Tertiary and Quaternary sediments and extrusives in a probable downthrown block.
3. The Cordillera Real, "backbone of the Bolivian Andes," with Tertiary or Mesozoic granitic and quartz monzonite intrusives forming peaks exceeding 21,000 feet and containing the rich tin-mining districts of Bolivia. A southern continuation of this element (without granite) is called the Cordillera Central.
4. The Cordillera Oriental consisting mainly of Ordovician and Devonian sediments. Carboniferous, Cretaceous, and Tertiary sediments are preserved in synclinal cores.
5. The Subandean zone or Andean foothills generally consisting of marine Devonian and continental post-Devonian sediments. The producing oil fields of southern Bolivia are located within this zone.
6. The open country called the Beni plain and Chaco plain in the north and south of Bolivia, respectively, present site of oil exploration activity.
7. The Brazilian shield exposing Precambrian basement.

The Paleozoic section in Bolivia includes rocks from all periods and has a maximum thickness on the order of 40,000 feet. Cambrian, Ordovician, Silurian, and Devonian dominantly shallow marine shales and sands were deposited throughout the Andean and Pampa areas and along the Brazilian shield. At the top of the Ordovician is an unconformity with apparent southward truncation of upper, middle, and lower Ordovician beds. A thin but widespread layer of glacial origin occurs at the base of the Silurian. Sediments of Lower, Middle, and Upper Devonian age conformably overlie the Silurian.

The Permo-Carboniferous sediments consisting of alternating glacial and interglacial deposits of continental origin in southern Bolivia. These become increasingly more marine toward the northwest. Lower Permian limestones known in Peru extend into Bolivia as far as the Subandean zone.

Post-Permian continental type deposition follows; however, age distribution is difficult to establish. A large gap in sedimentation probably exists between Permo-Triassic and Upper Cretaceous. Age of the Vitiacua limestone is questionable.

Thick continental Tertiary deposits fill parts of the Subandean zone and the Chaco and Beni plains, and are known in the synclines in the southern part of the Eastern Cordilleras. A Tertiary sequence of a different type has been found beneath the Quaternary of the Altiplano.

Basalts of Cretaceous, late Tertiary, and Quaternary age are present. Permian basalts found in Peru are rare or absent in Bolivia.

The conspicuous elbow of the Andes in the Arica-Santa Cruz corner possibly had its origin in Precambrian time and has guided the tectonics ever since.

A transcurrent fault zone is believed to have influenced Bolivia tectonics between Corumba-Santa Cruz and probably continuing through the Cochabamba-Oruro areas to the Chilean coast near Arica.

The present Bolivian Andes are the product of a late Tertiary orogeny. By comparison, the earlier orogenies of the Mesozoic and Paleozoic exerted but a mild effect on the structure of Bolivia.

Although lateral compression is generally believed responsible for the folding and faulting of the Andes and of their eastern foothills, some geologists now strongly postulate mostly vertical uplift created the present picture of this impressive mountain system in Bolivia.

11. Role of Sub-Andean Fault System in Tectonics of Eastern Peru and Ecuador: C. K. Ham and L. J. Herrera, Jr., Wm. Ross Cabeen & Associates, Lima, Peru

The Sub-Andean fault system is believed to be the most extensive tectonic feature of the South American Andes. The following discussion is restricted to its role in the tectonics of Peru and Ecudaor. A summary of the regional tectonic features and their histories for Peru and Ecuador is presented in order to orient the reader.

The fault system lies along the eastern front of the Andean ranges demarking the Andean uplift on the west and the potential petroleum province of the Sub-Andean basin on the east. The arcuate trace of this system as well as the trends of the Andean ranges and the Sub-Andean basin parallel the configuration of the western margin of the Brazilian and Guayana Precambrian shields.

The Andean uplift contains Precambrian and Mesozoic plutonic intrusions, Paleozoic metamorphic rocks, Paleozoic, Mesozoic, and Tertiary sedimentary rocks, and Tertiary volcanics. Metamorphic and sedimentary formations are highly deformed by folding and faulting and are commonly mineralized.

The Sub-Andean basin contains a thick sedimentary sequence of Paleozoic, Mesozoic, and Tertiary rocks which overlie a basement of Precambrian igneous and metamorphic rocks similar to that of the shield regions. Foreland folds developed east of the fault system are generally faulted along the eastern flanks and correspond structurally with the compression of deformation characteristic of the Andean uplift. Degree of folding and faulting diminishes eastward toward the shield regions.

The Sub-Andean fault system is an imbricate zone of west-dipping reverse strike faults along which the western blocks are elevated with respect to the eastern blocks. Stratigraphic separations of as much as 15,000 feet have been observed along faults of this system. It is possible that other types of movement, especially lateral movement, have occurred along this system during its history. A set of younger cross faults has subsequently offset the Sub-Andean system.

It is believed that the Sub-Andean fault system has played an important role in the migration of petroleum in the Sub-Andean basin.

12. "Backbone" of Colombia[1]: Cyril Jacobs, Consulting Geologist, Bogota, Colombia; Hans Burgl, Geology Professor, Universitad Nacional de Colombia; and Daniel L. Conley, International Petroleum (Colombia) Limited

The "backbone" of Colombia is the northern part of the Andes Mountains. The mountain system is here divided into the Eastern, Central, and Western Cordilleras. The Central and Eastern Cordilleras are separated by the down-faulted basin of non-marine Cenozoic deposition through which the Magdalena River flows in its middle and upper reaches. The valleys of the upper Cauca and upper Patía rivers mark the approximate boundary between the Western and Central Cordilleras. The Santa Marta and Perijá Mountains and the Pacific Coast Range are related to the Andean system.

[1] Prepared under auspices of The Colombian Society of Petroleum Geologists and Geophysicists.

The structural grain is north-northeast in the southern part of the Colombian Andes. Toward the north, major alignments are toward the northeast and northwest. The Sautatá arch connects the west Cordillera with the Darien Mountains of Panamá. The Guaviare arch links the Andes and the Guayana Shield.

The syenitic rocks of the Garzón-Guaviare region are the only known Precambrian west of the Guayana Shield. A record of marine Paleozoic sedimentation is preserved in the Eastern Cordillera and Perijá and Macarena mountains. Periods and epochs represented are: Late Cambrian (?), Early and Middle Ordovician, Middle Devonian, Mississippian, Pennsylvanian, and Permian. There is evidence of "Caledonian" orogeny. No Paleozoic marine sediments have been found west of the Central Cordillera.

Interbedded marine and terrestrial sediments and volcanics of Late Triassic and Early Jurassic ages crop out along the west side of the Upper Magdalena Valley, but on the northeast only continental sediments are present. A widespread marine invasion began in latest Jurassic time and affected the Andean region and its eastern foreland during the Cretaceous. The thick marine Cretaceous deposits east of the Central Cordillera and Santa Marta Mountains are a major source of oil. The area of the Bucaramanga massif was not submerged until Aptian time. West of the Central Cordillera, Cretaceous sediments are interdedded with porphyries and diabase flows.

Orogeny began in the Maestrichtian and reached a peak in the middle or late Eocene. Basic and ultrabasic rocks were intruded in the Western Cordillera and Pacific Coast Range regions. Tertiary marine deposition was restricted to regions west and north of the Andes. A thick non-marine Tertiary sequence elsewhere includes reservoirs containing more than 80 per cent of Colombia's proved oil reserves.

There was renewed orogeny at the close of the middle Oligocene, and intrusion of granodiorite batholiths in the Central Cordillera and southern Western Cordillera. A thick section of marine sediments was deposited west and north of the Andes in the late Oligocene and early Miocene. Elsewhere, down-warped and down-faulted belts continued to receive continental deposits.

The most recent orogenic and volcanic activity began in early Miocene and continues today, the orogeny affecting older positive belts and the Tertiary basins of marine deposition.

Wednesday Morning, April 26

Presiding: MASON L. HILL, VINCENT KELLEY

13. Summary of Tectonic History of Venezuela: ELY MENSCHER, Massachusetts Institute of Technology, Cambridge, Massachusetts

Present-day Venezuela may be divided into the following major structural provinces: Perija Mountains, Goajira-Paraguana arch, Maracaibo basin, Falcon, Venezuelan Andes, Carribbean Mountains (Coast Range and Serrania del Interior), Barinas-Apure basin, Eastern Venezuela basin, and Guayana Shield. With the exception of the shield and possibly the Goajira-Paraguana arch, all these provinces owe their essential development to Late Mesozoic or Tertiary tectonic events.

The pre-Cretaceous history is little known. Mid-Ordovician (?), Late Devonian or Early Carboniferous, and Permian (?) deformations may be postulated, but their trends and importance can not be evaluated at present. Toward the end of the Paleozoic, widespread uplift, accompanied by faulting and volcanism, raised the whole of the country above sea-level. Subsequent erosion resulted in positive features of structural origin, such as the Central Goajira massif, the Maracaibo platform, and the El Baul swell, which had an effect on Late Mesozoic and Tertiary sedimentation.

Beginning in the Late Mesozoic, the Caribbean Sea began an extensive transgression of northern and western Venezuela. The east-west-trending Caribbean orthogeosyncline developed in the area now occupied by the Caribbean Mountains; shelf conditions prevailed elsewhere.

Volcanism and major deformation of the Caribbean geosyncline began about Middle Cretaceous time, leading to the folding, faulting, and metamorphism of the previously deposited Cretaceous rocks. However, sedimentation, volcanism, and deformation, although on decreasing scale, continued throughout Late Cretaceous and Paleocene time and perhaps into the early Eocene. Dominant structural features in the Coast Range trend N. 70°–80° E.; wrench (strike-slip) faulting with horizontal displacements of several kilometers is common. It has been suggested that the over-all deformation of the Coast Range resulted from an east-west shear couple related to the development of the Caribbean sea area. Renewed uplift and south-southeastward thrusting, with related N. 60° W. strike-slip faulting, which reached a maximum in the Late Tertiary have caused the crumpling, faulting, and over-riding of the northern edge of the Eastern Venezuela basin to the south. The northern oil fields of the Eastern Venezuela basin are controlled either directly or indirectly by the consequent structures.

The Eastern Venezuela basin is an east-plunging asymmetrical elongate feature which was initiated in the late Eocene with the downsinking of the area south of the Caribbean ranges and east of the El Baul swell. Greatest depths are in the north close to the mountains. In addition to the north flank structures related to Coast Range uplift, east-west faulting with minor cross-faulting on the south flank, probably associated with the sinking of the basin, is important in the localization of oil fields.

The Perija, Maracaibo, Andes, and Barinas-Apure provinces owe their character as distinct units to the Tertiary Andean deformation, with the basins sinking as the mountains rose. The Cretaceous and Eocene oil fields of western Venezuela owe their existence to the Andean orogeny; the Middle to Late Tertiary fields are also linked to it. There is some indication that movements began first in the northwest (Sierra de Perija) during the Eocene, progressed southeastward across the more-or-less stable Maracaibo platform, reached the Andes at the close of the Eocene, and culminated in the Mio-Pliocene. The mountains, with dominant trend of N. 30° E. for the Perija and N. 45° E. for the Andes, are essentially complexly folded and faulted structural arches with high-angle reverse, normal, and wrench faults. Mountainward-dipping reverse faults are thought to bound their flanks. Both the Maracaibo and Barinas-Apure basins have asymmetrical cross sections with deepest zones close to the flanks of the Andes.

The Falcon province shows some relation to the Maracaibo basin and the Andes both in its sedimentation and in its deformational history. Originally a narrow trough, it received great thicknesses of sediments during the Middle and Late Tertiary and was finally folded and uplifted in the Pliocene, as well as in earlier Tertiary time.

An outstanding tectonic feature of northern Venezuela is a series of long east-west-trending right-lateral wrench faults that are located close to and roughly parallel with the coast. Best known of these are the