INTERNATIONAL LITHOSPHERE PROGRAM: UPDATE

by

Raymond A. Price and Edward A. Flinn

A major international research effort was launched recently to seek a better understanding of the complex evolution and dynamics of the lithosphere. This progress report not only reviews the scientific goals, plans and organization of the interdisciplinary program, but also focusses on the significance of some of its anticipated results. At a time of growing concern throughout the world about future mineral and energy resources, natural hazards and wise environmental management, the program heralds a potential conceptual renaissance in the earth sciences.

Background and Organization

The Lithosphere Program, a new international interdisciplinary research program in the solid earth sciences established by the International Council of Scientific Unions (ICSU) at the request of the International Union of Geological Sciences (IUGS) and the International Union of Geodesy and Geophysics (IUGG), is a natural sequel to a series of successful cooperative projects in the geosciences. These include the International Geophysical Year in 1957-58, the Upper Mantle Project in the 1960's, and the International Geodynamics Project in the 1970's. The new program aims to establish a better understanding of the development of the Earth, and particularly those aspects on which human society depends for its well being.

In 1977, IUGG and IUGS established an Inter-Union Task Group to consider the possibility of a successor to the Geodynamics Project (see EPISODES 1978, No. 3, p. 3-8). The Task Group's 1978 report proposed a new project on the dynamics, origin and evolution of the lithosphere; the proposal was approved by the IUGS Executive Committee in February 1979 and by the IUGG Council in December of that year, and an Inter-Union Steering Committee was established under the joint chairmanship of Dr. Carl Kisslinger, U.S.A. (representing IUGG) and Dr. Henning Illies, F.R.G. (representing IUGS). The Committee developed the organizational framework and constitution of the new program, approved by resolution of the ICSU Governing Board in September 1980. The Inter-Union Commission on the Lithosphere (ICL) was established to implement the program, and the national members of ICSU were urged to set up national committees to assist in developing programs for the new International Lithosphere Program (ILP).

To arrive at an effective balance between problem-oriented projects and those that were regionally oriented, the activi-

ties of the ILP were organized around national committees, international working groups and coordinating committees. National committees are responsible for coordinating ILP-related activities in the individual participating countries. The nine international working groups pursue the program's scientific objectives, each one being responsible for a specific interdisciplinary research topic or problem. Eight coordinating committees implement those aspects of the Program that draw upon the activities of several working groups, ensure the overall integration of the different components on both a regional and a global basis, and foster participation from developing countries.

Responsibility for planning and implementing the program as a whole lies with the ICL, which consists of the Chairmen of the working groups, the Chairmen of the coordinating committees, representatives of associated unions and ICSU committees, and a seven-member Bureau charged with administering the Commission.

At present, the Bureau members (who are appointed jointly by IUGS and IUGG and serve terms ranging from three to five years) are:

President: **Raymond A. Price**, Geological Survey of Canada, Ottawa, Canada (IUGS);

Secretary-General: **Edward A. Flinn**, NASA Headquarters, Washington DC, U.S.A. (IUGG);

Members: **Eugene Artyushkov**, Institute of Physics of the Earth, Moscow, U.S.S.R. (IUGG); **Umberto G. Cordani**, Institute of Geosciences, University of Sao Paulo, Brazil (IUGS); **J. Henning Illies**, Geological Institute, University of Karlsruhe, F.R.G. (IUGS); **Kurt Lambeck**, Research School of Earth Sciences, Australian National University, Canberra, Australia (IUGG); and **Seiya Uyeda**, Earthquake Research Institute, University of Tokyo, Japan (joint representative of IUGG and IUGS).

Inter-Union Steering Committee members met in Paris, France, in 1979 to produce the constitution of the ILP. Facing the camera in photograph at left are (L to R): T.J. Kukkamäki (Finland), D.A. Valencio (Argentina), Ma Zing-yuan (China), H.J. Zwart (Netherlands), and S. Uyeda (Japan).

The initial organizational meeting of the Bureau was held in Washington, U.S.A., in December 1980, when the terms of reference of the working groups and coordinating committees were established (see ILP Report No. 1, published in April 1981 and announced in EPISODES 1981, No. 2, p. 58). The first ICL meeting was held in London, Ontario, Canada, in July 1981 at which time the membership of the working groups and coordinating committees was finalized. The first issue of the ILP Newsletter is now being prepared.

Significance of program's objectives

Thanks to the great strides made in geodynamics research in recent years, earth scientists are developing, for the first time, a consistent and comprehensive perception of how the Earth works. It is now seen as a dynamic body, undergoing convection that is driven by its internal heat, and is expressed at the surface by relative movements with velocities of a few cm per year. Though very small, these can produce large effects over long intervals of time. Thus it has been concluded that new ocean floor is being continuously regenerated where hot buoyant mantle rises to the surface and spreads laterally, and that old ocean floor is being destroyed where cold lithosphere sinks back into the mantle. Continents, split by rifts, drift apart as oceans form between them and they grow by accretion as intervening oceans disappear. The oceanic lithosphere, which underlies about 70% of the earth's surface, is viewed as the upper boundary layer that cools, contracts and subsides as it flows away from the upwelling zone.

This simple model readily accounts for the variations in heat flow, elevation and age of the ocean floor rocks, as well as the otherwise perplexing conclusion that virtually all of the ocean floor is less than 200 million years old, and therefore formed during the last 5% of the Earth's history. Although our understanding of the oceanic crust is far from complete, the success of this elegant model has focussed attention on the continents, which, because of their composition and resultant lower mean density, are more buoyant and have survived through major periods of Earth's history.

If the old oceanic lithosphere has vanished forever, it is the continents that preserve what remains of the first 95% of the Earth's history. However, because the continents commonly contain the superimposed records of multiple discrete episodes of deformation, metamorphism and magmatism, the evolutionary history of continental lithosphere is complex and not as well understood as the imperfect evolutionary history outlined for the oceanic lithosphere. One of the principal motives behind the new program is the desire to fill this great gap in our knowledge of the part of the Earth that has provided virtually all of our known mineral and energy resources and the space in which we live.

Thus the central theme of the new program is the understanding of the current state, origin, evolution and dynamics of the lithosphere, with special attention to the continents and their margins. Further investigation of the sub-oceanic lithosphere will also be included. Moreover it is obvious that a full understanding of the lithosphere will depend on further research into the structure and composition of the deep interior of the Earth, and on the processes that operate there.

A key objective is to better understand just what the lithosphere is. It has been defined on the basis of seismic, thermal, and petrological properties, and on the basis of the parameters of isostatic flexures produced by surface loads. What remains to be established is how these different perspectives can be related to each other. The essential differences, physical and geochemical, between continental and oceanic lithosphere should be defined and explained. The depth to which these differences persist should be determined and the maintenance of these differences as the plates move should be accounted for. Equally important is the elucidation of differences in the lithosphere among various tectonic provinces in the continents. All of these problems require the combined application of a variety of geological, geophysical, geochemical, and geodetic techniques, and effective interdisciplinary cooperation.

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Another fundamental objective is to determine the contemporary relative motions of the various parts of the Earth's surface, and then to develop quantitative dynamic models of plate motions and intraplate deformation. New geodetic technology involving satellites and very long baseline interferometry will have to be combined with geophysical, geological and geomorphic analyses of near surface phenomena, as well as geochemical and geophysical studies of rocks that provide samples of the deep interior. The physical and chemical processes that characterize the interaction of the lithospheric plates along their common boundaries present several crucial problems. How does the deformation at these boundaries occur? How is elastic strain accumulated and released? How do conditions along the plate boundary change with time?

The answers to these questions are essential in applying plate tectonics theories to earthquake prediction. How magmas are generated, extruded and intruded at convergent and divergent plate boundaries and within plates is fundamental to understanding both the deformation of the Earth's crust and the origin of its mineral deposits, and should eventually advance the science of predicting and mitigating volcanic eruptions. In fact, the assessment, prediction, and mitigation of geological, geophysical, and geochemical hazards, both natural and those induced by human activities, have been identified as principal areas likely to benefit immediately from the program's research work. The ILP should contribute to developing improved methods for assessing the most likely locations of future great volcanic eruptions, earthquakes, tsunamis, landslides and other similar hazards.

It is fair to say that human activity has become a prominent geological force, and that the impact of man on the surficial portion of the lithosphere is now comparable with the results of natural geological processes. The rational use and protection of the environment, therefore, requires a full understanding of the intricate relationships among the component parts of the lithosphere, hydrosphere, biosphere, and asthenosphere, and of the influence of human activity on these. The program intends to provide the framework within which force systems, hazards, and environmental problems are investigated and understood.

The term "subduction" may have acquired a familiar ring, but in spite of all the simple cartoons depicting cross sections of subduction zones, the process itself is basically still an enigma. Almost nothing is known about how subduction begins, in comparison with, for example, the initiation of rifting. The fate of the oceanic sediments and of the subducted slab of the lithosphere itself are matters of conjecture. The mechanical and thermal state within the slab and the adjacent mantle, as well as the chemical and mineralogical changes that accompany subduction are problems of fundamental importance.

None of these problems is more pressing or more important than clarifying the nature, origin and evolution of the continental lithosphere. The uniformitarian dictum that "the present is the key to the past" provides an important starting point in this task. Another is comparative planetology, in which the recent information obtained from studies of nearby planets is applied to the analysis of the early stages in Earth's evolution. Identification and analysis of continental lithosphere that formed early in Precambrian time constitutes a challenge of considerable practical significance, because it offers the prospect of determining whether or not metallogenic provinces reflect ancient chemical heterogeneities in the continental lithosphere. The establishment of sound comprehensive models of the thermal, tectonic and geochemical evolution of the earth has been a prime goal of geosciences from the beginning. Progress toward accomplishing this elusive goal will require careful integration of geophysical studies of the crust and deeper lithosphere with geochemical and geological studies of surface rocks.

The strengthening of communication and mutual cooperation between geoscientists working primarily in the applied fields and those in basic research is a special objective of the ILP, and representatives of both groups are active in planning and

implementing the program. The research that will be undertaken is therefore expected to contribute to the techniques required in the search for additional supplies of non-renewable energy and mineral resources and in their optimum use.

Another area of special concern is the strengthening of geology, geophysics, geochemistry, and geodesy in the developing countries. Because the contributions of the earth sciences are essential to society, especially with respect to resource development and environmental management, it is important that these disciplines be encouraged in countries striving toward full development. Research under ILP will require data and analysis from all parts of the world, as well as the coordination and integration of facilities and talents in diverse disciplines. Specific projects that will contribute to the achievement of the programs goals are being designed keeping in mind the limits of the technical and financial capabilities and the national interests of the developing countries.

Specific scientific foci: the working groups

Recent Plate Movements and Deformation

(Working Group 1; Chairman: **K. Kasahara**, Japan; Vice-Chairman: **P. Vyskocil**, Czechoslovakia).

The objectives of this group are to measure the motion and deformation of the plates, both contemporary and those of the recent geological past, to establish the distribution of stress and strain in the lithosphere and develop models for the way these are concentrated, and to provide the basic data required for modelling of the internal mechanisms responsible for driving the plates. Polar motion and variations in the earth's rotation will be studied to determine possible relationships between these quantities and geophysical phenomena such as earthquakes and volcanic eruptions. A wide variety of geophysical, geodetic, and geological data will be used.

Phanerozoic Plate Motions and Orogenesis

(Working Group 2; Chairman: **R. Van der Voo**, U.S.A.; Vice-Chairman: **J. Monger**, Canada).

This group hopes to clarify the basic patterns of internal structure of Phanerozoic orogenic belts from the surface to upper mantle depths, study their kinematic evolution and their relationships to relative motion of the plates, elucidate the interactions of thermal regimes, magmatic, metamorphic, and deformational processes, and vertical and horizontal movements, and assess the implications of Phanerozoic orogenesis for the generation and evolution of the lithosphere, the continental crust, and the upper mantle.

Folded Cambrian sedimentary rocks, southern Canadian Rocky Mountains: analysis of folds such as these provides estimates of crustal foreshortening during the Phanerozoic.

Proterozoic Lithospheric Evolution

(Working Group 3; Chairman: **A. Sidorenko**, U.S.S.R.; Vice-Chairman: **A. Kröner**, F.R.G.).

The principal tasks here are to elucidate the basic patterns of structure and composition of the Proterozoic lithosphere and

the implications for problems of growth of continents and the differentiation of the mantle and crust, to characterize Proterozoic tectonic regimes, including the kinematic evolution of Proterozoic orogenic belts, and to evaluate the role of plate tectonics in Proterozoic orogenesis and lithospheric evolution.

Specific topics to be studied include the structure and composition of the lithosphere in Proterozoic tectonic provinces, Proterozoic thermal evolution of the Earth, determination of Proterozoic polar wandering curves, the origin and evolution of Proterozoic granites and related rocks, and characterization of the Proterozoic sedimentary environments (with special emphasis on evidence of ancient life).

Wadi Ghadir, Eastern Desert of Egypt: this complex is part of a late Precambrian rock assemblage with sheeted dykes interpreted as indicating that present-day plate tectonic processes operated in this area at least 800 Ma ago. (Photo courtesy A. Kröner)

The Archean Lithosphere

(Working Group 4; Chairman: **B. Windley**, U.K.; Vice-Chairman: **R. Hargraves**, U.S.A.).

This group intends to outline the nature and dynamics and the magmatic and metamorphic processes of the Archean in order to explain the origin of the lithosphere and to reconstruct the earlier stages of its evolution. They hope to clarify the physical and chemical processes that prevailed during the initial phases of Earth's history, and to elucidate the origin of the Earth's atmosphere and hydrosphere through investigation of processes of weathering, erosion, and sedimentation during the Archean. Comparative planetological studies will be an important part of the activities of this group.

Intraplate Phenomena

(Working Group 5; Chairman: **D. Roberts**, U.K.; Vice-Chairman: **C. Beaumont**, Canada).

This group is concerned with clarifying the nature and origin of intraplate phenomena such as zones of subsidence marked by sedimentary basins in the continents and their margins, plateau uplifts, oceanic plateaus, seamounts, intracontinental rifts, zones of intraplate crustal compression and faulting, seismicity, and volcanism.

Nature and Evolution of the Oceanic Lithosphere

(Working Group 6; Chairman: **J. Francheteau**, France; Vice-Chairman: **R. Larson** U.S.A.).

The structure and composition of the oceanic lithosphere, the processes involved in its generation and evolution, and the implications of these processes for the geochemical evolution of the Earth are the prime areas of concern here. Valuable information on metallogenesis will be provided by investigations of magmatic and hydrothermal activity at spreading centers. Emphasis will be placed on the older parts of the oceanic plates; the nature and origin of such oceanic features as aseismic ridges, oceanic plateaus, and microcontinents will also be studied.

Paleoenvironmental Evolution of the Oceans and the Atmosphere

(Working Group 7; Chairman: **K. Hsu**, Switzerland; Vice-Chairman: **V. Krasheninnikov**, U.S.S.R.).

The objectives of this working group are to outline the global record of evolving paleoenvironments and paleocirculation of the Earth's oceans and atmosphere during the Cenozoic and Mesozoic, as preserved under the oceans, to integrate this with the stratigraphic record that is preserved on the continents, trace this record back through time as far as possible, and to assess the implications of this global record for the evolution of the hydrosphere and the atmosphere, as well as the impact of human activities on them.

Subduction, Collision, and Accretion

(Working Group No. 8; Chairman: **K. Kobayashi**, Japan; Vice-Chairman: **H. Gribidenko**, U.S.S.R.).

The principal task here is to clarify the geodynamical processes that occur at convergent plate boundaries, and to study their implications for global tectonics and the evolution of the Earth. Specific investigations include: (i) the structure, composition, mechanical and thermal state, and the ultimate fate of the subducting and overriding lithospheric plates; (ii) related seismicity, crustal deformation, internal movements, magmatism, metamorphism, metallogenesis, and geothermics of subducting slabs; (iii) processes in the deeper mantle related to subduction - chemical differentiation, phase transformations, convection in the mantle; (iv) processes controlling the initiation and termination of subduction, including integrated geological, geophysical, and geochemical studies of paleo-subduction zones; (v) the nature and significance of the collision-accretion process, including integrated geophysical and geological investigations of present-day accretion and collision zones, and of the terranes that have been accreted to continental plates during the geological past.

Processes and Properties in the Earth that Govern Lithospheric Evolution

(Working Group No. 9; Chairman: **C. Froidevaux**, France; Vice-Chairman: **N. Sobolev**, U.S.S.R.).

This group will study the properties of mantle rocks and minerals under conditions of pressure and temperature appropriate to the interior of the Earth, investigate the internal composition and thermodynamical state of the Earth, and study the deep-seated physical and chemical processes that govern the generation and evolution of the lithosphere. The work will involve coordinating laboratory and theoretical investigations, including the measurement of many physical and chemical properties. Mechanisms of magma generation, extrusion, and intrusion will also be examined.

Coordination of scientific operational units

Environmental Geology and Geophysics

(Coordinating Committee 1; Chairman: **V. Magnitsky**, U.S.S.R.; Vice Chairman: **J. Arnould**, France).

The principal task of this committee is to develop effective communication and cooperation between appropriate scientific working groups and those individuals and organizations concerned primarily with applying scientific knowledge to the assessment, prediction and mitigation of geological and geophysical hazards. As with other coordinating committees, the membership is drawn partly from the working groups. Specific areas of interest are volcanic eruptions, earthquakes, tsunamis, landslides, flash floods, climatic changes, the gradual subsidence of coastal areas, and the slow deformation of the foundations of engineering structures.

Mineral and Energy Resources

(Coordinating Committee 2; Chairman: **R. Hutchinson**, Canada; Vice-Chairman: **D.H. Welte**, F.R.G.).

This committee ensures that there is effective collaboration between the working groups and those scientists concerned primarily with exploration for mineral and energy resources. The vast body of new concepts, scientific technology, and scientific data produced in the search for mineral and energy

resources is of fundamental importance to the program and must be integrated with the advances in scientific understanding of the Earth that are likely to come out of the working groups' research and which will be useful to exploration geoscientists.

Geosciences Within Developing Countries

(Coordinating Committee 3; Chairman: **D.E. Ajakaiye**, Nigeria; Vice-Chairman: **P. Nutalaya**, Thailand).

Committee members here are concerned with developing mechanisms for the effective participation of earth scientists from developing countries on the basis of the common scientific interests shared by those countries and ILP. The committee is responsible for liaising with the specific commissions, committees, and other organizations concerned with strengthening earth sciences in the developing countries.

Evolution of Magmatic and Metamorphic Processes

(Coordinating Committee 4; Chairman: **V. Sobolev**, U.S.S.R.; Vice-Chairman: **H. Zwart**, Netherlands).

The objective of this committee is to integrate and synthesize the results of studies of magmatism and metamorphism in a global context and on a time scale that includes the whole history of the Earth. Topics being studied are the patterns of variation in time and space of different kinds of magmatic and metamorphic rocks, and the mineralogical, petrochemical, and isotopic characteristics of these rocks.

Structure, Composition of the Lithosphere and Asthenosphere

(Coordinating Committee No. 5; Chairman: **K. Fuchs**, F.R.G.; Vice-Chairman: **T.H. Jordan**, U.S.A.).

This committee coordinates investigations aimed at establishing the detailed structure and composition of the lithosphere and asthenosphere on the basis of their mechanical, thermal, and geochemical properties, the essential differences between continental and oceanic lithosphere, and the nature and significance of lateral variations in these properties to the evolution of the earth. A wide variety of disciplines are involved, including seismology, rheology, thermal state, geodesy, geochemistry, and electromagnetic sounding.

Continental Drilling

(Coordinating Committee 6; Chairman: **H. Vidal**, F.R.G.; Vice-Chairman: **N. Laverov**, U.S.S.R.).

This committee is developing mechanisms for international and interdisciplinary communication in the scientific use of opportunities for continental deep drilling, and the results of measurements made in connection with such drilling. It will investigate the possibilities offered by new instrumental technology for scientific measurements in deep boreholes, and encourage international collaboration in deep drilling of the continents.

Data Centers and Data Exchange

(Coordinating Committee 7; Chairman: **M.A. Chinnery**, U.S.A.).

The tasks of this committee are: (i) to provide a channel of communication for the working groups, other program participants, and national committees on geoscience data management, and ensure the exchange of information and project requirements concerning data management; (ii) to prepare and regularly update a directory of data centers and data catalogs for use in ILP and by the international geoscientific community; (iii) to bring to the attention of ICL any data management matters which may require action or recommendation to other bodies; and (iv) to consider the possibility of establishing under international support several major data centers to which investigators might come as guest workers in order to have access both to large data sets and to computational facilities for analyzing the data.

Coordinating Committee of National Representatives

(Coordinating Committee 8)

This committee will consist of representatives of all the national committees; it will meet during the ICL meetings, participate in the business meetings, and report on national

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1 Recent Plate Movements and Deformation	1 Environmental Geology and Geophysics
2 Phanerozoic Plate Motions and Orogenesis	2 Mineral and Energy Resources
3 Proterozoic Lithospheric Evolution	3 Coordinating Committee for Geosciences Within Developing Countries
4 The Archean Lithosphere	4 Evolution of Magmatic and Metamorphic Processes
5 Intraplate Phenomena	5 Structure and Composition of the Lithosphere and Asthenosphere
6 Nature and Evolution of the Oceanic Lithosphere	6 Continental Drilling
7 Paleoenvironmental Evolution of the Oceans and the Atmosphere	7 Data Centers and Data Exchange
8 Subduction, Collision, and Accretion	8 Coordinating Committee of National Representatives
9 Processes and Properties in the Earth that Govern Lithospheric Evolution	

BASIC RESEARCH ↔ APPLICATIONS

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PROPERTIES - PROCESSES - DYNAMICS

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TIME → EVOLUTION

The above schematic charts highlight the inter-relationship between the various organizational components of the program.

ABOUT THE AUTHORS:

Dr. E.A. Flinn is Chief Scientist of the Geodynamics Program, National Aeronautics and Space Administration Headquarters in Washington, D.C., U.S.A. and Secretary General of the International Lithosphere Program. A theoretical seismologist before joining NASA, his main scientific interests now are in applying space technology to geology, geophysics and geodynamics.

Dr. R.A. Price, former professor and head of the Department of Geological Sciences at Queen's University in Canada, has just joined the Geological Survey of Canada as Research Scientist in charge of Special Projects including production of the Geological Map of Canada. President of the ILP and Foreign Secretary of the Canadian Geoscience Council, he lists thrust faulting, evolution of the Southern Canadian Rocky Mountains and Cordilleran tectonics as his prime scientific interests.

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activities that may be relevant to the program. The committee will take advantage of opportunities for coordinating national research activities, as well as for developing co-operative research programs within individual regions or on special topics that are of mutual interest to several countries.

The immediate future

Schedules of future meetings for program review and planning purposes were outlined during the ICL organizational meeting in July. These include ICL meetings in the fall of 1982 in the U.S.A. (to be held during a national geoscience meeting), in the F.R.G. in 1983 (during the IUGG General Assembly), and in the U.S.S.R. in 1984 (during the International Geological Congress). The newly-formed working groups and coordinating committees are planning their own meetings for 1982, and some are organizing symposia and conferences in cooperation with other organizations such as the Unesco Commissions, IUGG and its Associations, IUGS and the IGCP. Several symposia at the Fifteenth Pacific Science Congress in New Zealand in 1983, and a number of interdisciplinary symposia at the 1983 IUGG General Assembly, will be co-sponsored by ICL. An overall formal synthesis and evaluation of the principal achievements will be submitted to the sponsoring unions in 1985. It is anticipated that this evaluation will include specific recommendations, as warranted, for changes in the organization and activities (though not the basic objectives) during the second half of the program.

The constitution and the organizational framework of the ILP have ensured a forum for active participation by all interested countries, organizations and individuals. They have taken full advantage of the advice and recommendations offered during the two-year course of deliberation and program preparation. They are aimed at establishing and maintaining unity and scientific integrity in a program that has the potential for becoming one of the most important scientific activities for the future of mankind. It is now up to us, the participants, to realize this potential.

(Further information about ILP and its publications are available from the Secretary-General of ICL, E.A. Flinn, Mail Code ERG-2, NASA Headquarters, Washington, DC 20546, U.S.A.).

The first ICL meeting was held in July of this year during the IASPEI General Assembly in London, Canada. Chairing this session are Dr. R.A. Price (President of ILP) and Dr. E.A. Flinn (Secretary General); at the board is Dr. A. Beus, (U.S.S.R.), a member of Working Group 3.

Ray Price (left) confers with Ted Flinn and Helen Patterson, assistant to Dr. Flinn.