Summary of Significant Results

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INTRODUCTION

During the Apollo-Soyuz Test Project (ASTP) of July 1975, 28 separate science and technology experiments were conducted by the Apollo crew. One of these, the Earth Observations and Photography Experiment, is the subject of this volume. The basic objective of the experiment was to utilize the special capabilities of trained observers (namely the three U.S. astronauts) in visually studying and photographing specific Earth features, processes, and phenomena. Areas were selected for visual observations and photography on the basis of their interest to specialists in the fields of geology, desert studies, oceanography, hydrology, and meteorology.

The success of the experiment is reflected in the plethora of excellent photographic and observational data acquired during the mission. These data, which include transcripts of astronaut observations and transparencies of more than 1400 70-mm photographs, were made available to the experiment team and other interested scientists. The reports included in this volume are the result of an extensive research program that drew investigators from government agencies, academic institutions, and research organizations in Australia, Barbados, Brazil, Canada, Egypt, India, Israel, Qatar, Turkey, and the United States.

In the last 10 years, scientists have become increasingly involved in monitoring Earth resources and in studying the processes and phenomena that affect the environment. Orbital photographs of the Earth have become important tools in such investigations. The great areal coverage of orbital photographs facilitates studies of regional relationships and of broad distributions. Orbital photographs also provide information on remote, inaccessible, and unexplored areas where they can be used for reconnaissance surveys.

To complement the photographic data, visual observations from Earth orbit are important because human observers can often see more color and textural variations than will be recorded on the most sensitive photographic film. This capability is related to the extensive dynamic range and color sensitivity of the eye and to the speed with which the eye/brain system can interpret what is seen and can distinguish what is significant. Moreover, one of the inherent advantages of visual observations is concerned with the ephemeral nature of many scientifically interesting features such as internal waves, which are only visible in sunglint for a very short period of time. Unlike unmanned satellites, trained human observers can easily locate, identify, describe, and photograph such "targets of opportunity," largely because the observers can exploit various degrees of obliqueness and Sun-elevation angles to scan the scene below.

The schedule for Earth observations and photography during ASTP called for three types of tasks: (1) visual observations of selected Earth features, (2) handheld-camera photography to document observations, and (3) stereo mapping photography of areas of significant scientific interest. To ensure the successful completion of these tasks, an extensive implementation effort, consisting of crew training, flight planning, and mission support, was initiated 1 year before the mission. A detailed report on the implementation

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effort has been published elsewhere;[1] a brief overview is given here.

The ASTP crewmembers devoted approximately 60 hours to attending lectures designed to familiarize them with the types of Earth features they would observe and photograph. These lectures were given by members of the Earth observations team, a group of specialists assembled to assist in the planning and execution of the experiment. Classroom lectures provided the crewmembers with background information on the basic fields of investigation (geology, desert studies, oceanography, hydrology, and meteorology) and familiarized them with the geography of areas scheduled for observations and photography.

Aircraft training flights, known as flyovers, gave the crewmembers practical experience in observing, describing, and photographing Earth features; the flyovers also provided practice in operational procedures such as handling cameras, lenses, film magazines, and the tape recorder. Seven different flyover exercises were planned and flown in California, Florida, southwestern and northwestern United States, and along the Gulf Coast and East Coast. For each of these flyovers, a visual observations book was prepared to show the flight route and the targets for observation and photography. The flyover exercises gave the ASTP crew valuable practice in selecting the optimum viewing conditions for specific features. For example, they found that high Sun angles were best for observing subtle color variations such as those marking plankton blooms in the ocean; on the other hand, low Sun angles enhanced relief and facilitated observations of geological features such as faults and fractures.

Because of the short duration of the ASTP mission (9 days), only a limited amount of time was available for the Earth Observations and Photography Experiment, and each target had to be specified ahead of time and scheduled in the ASTP Flight Plan. The selection of targets before the mission involved a number of considerations including the recommendations from members of the Earth observations team, the times available in the Flight Plan for the experiment and the locations of areas that would be overflown by the spacecraft during these times, and the optimum viewing conditions for each target.

The final site list consisted of 11 photographic mapping passes and 60 visual observation targets. The term "mapping pass" refers to vertical stereostrip photography acquired with a 70-mm Hasselblad data camera that was bracket mounted in a spacecraft window and used either a 60- or 100-mm lens. The Hasselblad data camera was equipped with an intervalometer that triggered the camera shutter every 10 seconds for the 60-mm lens and every 6.25 seconds for the 100-mm lens, thus providing 60-percent overlap between successive frames. These photographs could be studied stereoscopically, which provided a three-dimensional view and created an illusion of depth. In addition, the vertical photographs enabled the study of large-scale landforms and the preparation and correction of topographical base maps.

Visual observation targets were photographed with a handheld 70-mm Hasselblad reflex camera and a 35-mm Nikon camera. The Hasselblad camera used a 50- or 250-mm lens and was equipped with a single-lens reflex mechanism that permitted the astronaut to accurately aim the camera at the target. The 35-mm Nikon camera also incorporated through-the-lens light metering and a motorized film advance in addition to reflex viewing. The oblique photographs obtained with these cameras presented a perspective view more readily understood than a vertical view and were extremely useful for documenting visual observations and targets of opportunity.

In addition to the photographic equipment, the experiment flight package included visual observations aids designed to assist the astronauts in making the best use of the Flight Plan time allotted to the experiment. These aids consisted of the Earth Observations Book, the World Map Package, a color wheel, a ground scale, and an enlarging telescope.

During the ASTP mission, members of the Earth observations team provided technical support at the mission control center at NASA Lyndon B. Johnson Space Center. This real-time sup-

[1] El-Baz, Farouk: Astronaut Observations From the Apollo-Soyuz Mission. Vol. I of Smithsonian Studies in Air and Space, Smithsonian Institution Press (Washington, D.C.), 1977.

port was necessary (1) to ensure that any questions asked by the crewmembers could be answered immediately, (2) to monitor weather conditions so that cloud-covered targets could be rescheduled, and (3) to relay information on short-lived phenomena such as volcanic explosions, hurricanes, or outbreaks of red tide. The science support team also monitored numerous ground investigations conducted in support of the experiment and exchanged data between the crewmembers and the research parties. Concurrent aircraft flights, land investigations, and ocean surveys in many parts of the world were part of the largest ground-truth collection program conducted in support of any manned space mission. The data supplied by these surveys were used in the postmission analyses of ASTP observations and photography.

After the mission, the crewmembers attended debriefings to review the operational and scientific aspects of the experiment. These debriefings allowed the experiment team to more fully discuss the observations made by the crewmembers. Transcripts of these debriefings were made available to the teammembers and were used in the ASTP data analysis.

SIGNIFICANT RESULTS

In the following paragraphs, a summary is given of the significant results of the ASTP data analysis. The discussion is structured according to the fields of investigation including geology, desert studies, oceanography, hydrology, and meteorology.

Geology

In this volume, geological investigations may be grouped into two categories: (1) regional tectonic studies and (2) volcanic features and astroblemes. Most of the regional tectonic studies were concerned with identifying and mapping fault, fracture, and fold patterns as well as lithologic features. Other investigations pertained to the detection and identification of circular ground patterns that might be volcanic features or astroblemes (ancient meteorite-impact scars).

During ASTP, studies of global tectonic patterns included observations of southern California, the Red Sea/Levantine Rift zone, the Western Desert of Egypt, southern Spain, and South Australia. These photogeological investigations of regional tectonic settings profited by the extensive areal coverage of the ASTP data, which made it easy to trace large-scale fault and fold patterns and to perceive structural relationships. In addition, the color sensitivity and good resolution of the photographic film often allowed interpreters to make gross lithologic discriminations on the basis of subtle color and textural variations. Some of the most useful products of these investigations were geologic maps that presented all the pertinent details recognized and identified on the photographs and, in many cases, checked in the field.

The complex geology of the southwestern United States is, in part, the result of differential movement occurring between large parts of the Earth's crust known as the Pacific and American plates. This area of crustal fracturing is generally characterized by a northwest-southeast structural grain. Dominating the region is the northwest-trending San Andreas Fault, a transform fault along which large-scale horizontal motion occurs as a result of shear between the two plates. The geology of the area is further complicated by the intersection of an east-trending fracture zone, which is reflected in southern California by the Transverse Ranges.

A sequence of ASTP mapping photographs was obtained over the San Andreas Fault and the central Transverse Ranges in southern California. A study of the remarkably clear ASTP photographs facilitated the identification of many known structures and provided insights into previously unknown structural elements and patterns. Within and bounding the San Gabriel Mountains in the Transverse Ranges, a previously unrecognized pattern of east-northeast-trending lineaments and the lobate character of the mountain front were recognized. These observations offer new perspectives to possible interpretations of the San Gabriel Mountains, which may be a series of tectonically emplaced shingled slabs.

Geological investigations of the Red Sea/Levantine Rift zone during ASTP included observations and photography of the Afar Depression, the northwestern Gulf of Suez, the Levantine Rift, and southeastern Turkey/northwestern Iran.

Located at the junction of the Red Sea, the Gulf of Aden, and the East African Rift systems, the Afar Depression is a triple junction, an area of crustal separation and outward spreading in three directions. Early in this century, geologists first speculated that the remarkably similar shapes of the opposing coasts of the Red Sea and Gulf of Aden might indicate that Africa and Arabia were once a single continental block before crustal separation occurred. Since that time, geological, geophysical, and photographic evidence have provided further support for this hypothesis. According to modern plate tectonic theory, the northward translation and counterclockwise rotation of the Arabian plate away from the Afar spreading center resulted in the opening of the Red Sea and the Gulf of Aden, in the left-lateral strike-slip faulting along the Levantine Rift, and in the collision and subduction of the Arabian crustal plate beneath the Eurasian plate.

Geographically, the Afar Depression is a triangular region bounded on the west by the Ethiopian plateau, on the south by the Somali plateau, and on the east and northeast by the Red Sea and Gulf of Aden. When the original geographic positions of Africa and Arabia before separation are reconstructed, the Afar region is an area of overlap. Because of this, geologists generally agree that the Afar Depression is oceanic crust created since the breakup of the Afro-Arabian plate. For the most part, geologic data support this interpretation except for the anomalous occurrence of two old, nonvolcanic massifs, the Danakil Alps and the Aisha hills.

Paleomagnetic data have shown that the Danakil massif is a splinter of the Ethiopian plateau that has been rotated into Afar by the opening of the Red Sea. However, the position of the Aisha hills, which extend northward from the Somali escarpment, cannot be easily explained. The ASTP mapping photographs taken over the Afar region were studied and used to support a new interpretation for the occurrence of the Aisha hills. This theory states that the hills have moved north-northeastward to their present location by strike-slip movement along the Marda Fault zone, which stretches more than 900 km across the Horn of Africa. In this case, the ASTP photographs provided additional evidence to support a new model.

Farther north, over the western coast of the Gulf of Suez, ASTP photographs were studied in an investigation of regional structural patterns. Near-vertical and oblique ASTP photographs were used to identify faults; Landsat images were used for planimetric mapping; and aerial photographs were used to verify the mapped fault lines. The photographs showed that the area was characterized by a series of positive and negative fault blocks. On the ASTP photographs, three positive and two negative crustal blocks bounded by long east-northeast-trending faults could be identified. These results supported the theory that vertical tectonics were responsible for the development of the fault pattern in the area.

The northern extension of the Red Sea Rift is known as the Levantine Rift, a complex fault system extending from the Gulf of Aqaba northward into Turkey. It is a zone of left-lateral strike-slip faulting marking a transform plate boundary between Africa and Arabia. The southern part of the fault zone is characterized by a linear rift along which the Dead Sea and Sea of Galilee lie. Both Skylab and ASTP photographs were available for this part of the fault zone. Taken with different Sun angles and look directions, the photographs provided different types of information. It was found that vertical photographs were useful for synoptic, orthogonal mapping; low-Sun-angle photographs emphasized subtle structural and topographic variations; and oblique photographs provided regional views of fault systems.

Over the northern part of the Levantine Rift in Syria and Turkey, a vertical strip of ASTP mapping photographs produced a new structural interpretation that shows a splintering of the Levantine Rift zone northward toward the East Anatolian Fault zone in Turkey. This pattern was observed by the Apollo crewmembers who described the northern part of the Levantine Rift as a fan-shaped complex composed of three major curvilinear fractures.

In southeastern Turkey and northwestern Iran, ASTP photographs revealed complex structures that are probably also related to the motion of the Arabian plate away from the Afar spreading center. The general geologic setting of this area is characterized by two major tectonic blocks. The interface between the two blocks is paralleled by a major fold belt, slightly concave to the southwest. The structures in this area could be interpreted as resulting from the northward movement and subduction of the Arabian plate. In addition, a major strike-slip fault that was identified in the photographs probably corresponds to the Anatolian transform fault and suggests that plate movement may be continuing at the present time.

A number of mapping and handheld-camera photographs were taken over the Western Desert of Egypt. An investigation of lineaments displayed in these photographs provided information on the structural setting of the area. The ASTP findings were supplemented by collateral data such as Landsat images, aerial photographs, topographic and geologic maps, and field observations.

The northward movement of the African crustal plate has been used to explain the formation of the Sierra Nevadas in southern Spain. These mountains are related tectonically to the Rif Atlas in Morocco and represent the westernmost element of the Alpine orogenic belt. Excellent near-vertical ASTP photographs of southern Spain were used to identify and map lineaments and fold patterns. Analyses of these patterns revealed that they could be the result of compressional and tensional stresses. According to this model, a major compressional stress environment, generated by counterclockwise rotation of the Iberian Peninsula together with northward movement of the African plate, resulted in slowly closing jaws. Later relaxation of the stress field or a change in the direction of plate movement resulted in a tensional environment.

Apollo-Soyuz color photographs of the North Flinders Ranges in South Australia were analyzed to determine the characteristics of regional fold structures and to identify major folds, faults, and other lineaments. A good correlation between the photogeologic interpretations and geology on previously published geologic maps was found. Although remote, this area had already been extensively mapped by Australian geologists. However, if the ASTP photographs had been available earlier, they would have been a powerful tool for stratigraphic work, geologic mapping, and the interpretation of the large and complex structures of the region.

Terrestrial craters resulting from meteorite impacts are now known to have been more numerous than previously believed. These include relatively recent impact craters (e.g., Meteor Crater in Arizona) and ancient impact scars, or astroblemes (e.g., the Sudbury structure in Canada). During ASTP, a study was made of circular features in Brazil, Libya, and Mexico to increase our knowledge of the interaction of the Earth and meteorite bodies and to identify new areas for efficient ground exploration. The most significant result was the discovery of a new astrobleme in Brazil. Named the Riachão Ring after the nearest city, the feature was invisible on airborne radar and near-infrared satellite images. However, the circular structure, which is 4 km in diameter, was easily recognized and photographed by the orbiting astronauts. Based on this discovery of a probable meteorite impact crater, a field trip was conducted and samples collected which are being analyzed to assess this interpretation.

The ASTP astronauts also obtained excellent photographs of volcanic structures and observed an eruption of Mount Etna. In Mexico, a feature that had been previously identified as a possible meteorite-impact site was found to be a rhyolitic ash ring formed by a volcanic steam explosion.

Desert Studies

Photographs taken from Earth orbit provide a very practical means of studying remote, inaccessible, and unexplored desert regions. Because of their great areal coverage, these photographs are especially helpful in mapping regional patterns of sand distribution, in studying large-scale dune morphology, in determing the direction of sand movement, and in determining the location of areas where migrating dunes present a threat to cultivated land. In addition, the natural color of orbital photographs facilitates the detection of subtle color variations, which could provide information on the chemical makeup and relative age of desert sands. For these reasons, desert studies were an important part of the Earth Observations and Photography Experiment, and excellent data were obtained of desert regions in Australia, Egypt, Argentina, Angola, and Arabia. The ASTP effort made a significant contribution in expanding the geological community's interest in desert investigations.

The ASTP mapping photographs of longitudinal dunes in the Strzelecki Desert of Australia reveal an increase in red color as the distance downwind from the source of sand increases. Reddened sands, due to iron-oxide coatings on individual grains, occur in deserts throughout the world, and the degree of reddening in sands of uniform aridity and source may be used to determine sequences of depositional events.

In Egypt, ASTP mapping and handheld-camera photographs showed regional and local color zones that were later checked in the field by a team of geologists from the Smithsonian Institution and Ain Shams University, Cairo, Egypt. In one photograph covering the desert just west of the Nile Delta, three distinct color zones were identified. These were correlated in the field with desert pavement, relatively active sand with sparse vegetation, and arable soil composed of quartz sand, clay, and calcium carbonate particles. The identification of the previously unknown extent of an arable zone west of the cultivated Nile Delta attests to the value of ASTP color photographs in desert studies.

A study was also made of sand distribution in the Western Desert to provide a descriptive basis for future desert studies in this area. The trends of dunes in the Western Desert generally veer in a clockwise direction around a center near Kufra Oasis in Libya. Dune orientations change from north-northwesterly in the northern desert to north-northeasterly in the south. The ASTP photographs revealed a distinct pattern of sand deposition and dune formation that was closely related to topography and prevailing wind patterns.

The ASTP data on Egypt were also used to study the feasibility of comparing orbital photographs taken in different years to detect temporal changes. The ASTP photographs of the Nile Delta and the Oweinat Mountain region were compared to Gemini and Apollo photographs of the same areas. West of the Nile Delta, an increase in vegetation of approximately 1108 km^2 in 10 years was identified. Near Oweinat Mountain, at the borders between Egypt, Libya and Sudan, it was found that sand patterns had shifted 2.5 km over a 6-year period.

In Argentina, ASTP photographs of the Monte Desert in southeastern San Juan Province revealed two unusual and little-known dune fields. These fields display complex dune patterns that are controlled by a number of factors including the rainfall, the underlying and surrounding topography, the wind regime, and the amount of sediment available. The ASTP observations resulted in Argentinian interest in performing in-depth studies of these areas.

Photographs in semiarid southeastern Angola revealed landforms that provide evidence of climatic change. Suspected karst features imply more humid conditions; whereas ancient eroded sand dunes indicate a more arid climate. Also, the ASTP photographs of Arabia showed reddened dunes oriented along the prevailing wind directions. These photographs were also used to distinguish the exposed rock surfaces on the basis of color and texture.

Oceanography

The ASTP astronauts collected a plethora of photographic and observational data in support of studies of the world's oceans. Orbital photographs have proved valuable in documenting large-scale ocean features and circulation patterns. Many of these features, such as ocean currents, are important to the shipping and fishing industries. Other features, such as large-scale cold water eddies, are important because they act as mechanisms of energy dispensation, in some cases as productive fisheries, and as hiding places for submarines because of their effect on sound waves. Color variations in ocean waters are also significant because accurate measurements of water color can help identify distinct ocean currents, eddies, and areas of biological productivity.

The ASTP crewmembers obtained a number of excellent photographs over the world's oceans. However, the usefulness of some of these photographs was curtailed by the lack of information on their exact geographic positions. Therefore, to increase the scientific usefulness of these photographs, an effort was made to quantitatively define their locations. The methods used were based on photogrammetry, on a knowledge of the groundtracks of the spacecraft and the times during which the photographs were taken, and on a comparison with weather satellite imagery.

Visual observations were especially important in locating, identifying, describing, and photographing many ocean features, largely because many of these features are only visible under specific viewing conditions. For example, sunglint is especially helpful in studying water surface texture and in identifying internal waves. On the other hand, high Sun angles are useful in emphasizing subtle water-color variations that could mark current boundaries and upwelling areas.

Perhaps the most significant ocean observation was the recognition of the surface manifestations of internal waves off the coast of Thailand and the Strait of Gibraltar. Internal waves are little-understood ocean features similar to surface waves but orders of magnitude larger. They occur within the ocean at temperature or density discontinuities between water layers. Seen in sunglint, the scum lines often associated with internal waves facilitate their observation from space. Because observation periods are brief, many ocean features observed during ASTP were not visible in sunglint for more than 5 to 10 seconds. This emphasizes the importance of having trained observers who can rapidly recognize and photograph such targets of opportunity.

Photographs of the Sun's reflection also provided information on the texture of the sea surface. For example, a series of mapping photographs taken between Tunisia and Sicily included areas of sunglint. These areas revealed ocean surface phenomena related to turbulence, including possible internal waves. Photographs of the eastern Gulf of Mexico also documented patterns in the sunglint, which were interpreted as indicators of the cyclonic shear zone of the Gulf Loop Current.

The ASTP ocean photographs also revealed a wide variation in water color, which could be a function of Sun angle, water surface roughness, suspended sediments, water depth, and biological productivity. For example, around Cape Cod the natural color of the ASTP photographs enabled the recognition of light blue-green areas marking shoals and suspended sediments.

In South America, photographs and observations of the Orinoco River Delta showed discrete water-color zones that reflect the mixing of the sediment laden Orinoco outflow with the water of the tropical Atlantic. The ASTP crewmembers thought they could observe turbid water associated with the Orinoco outflow extending past the island of Barbados. To support these observations, the Bellairs Research Institute, McGill University, sponsored three cruises from Barbados in July 1975. Measurements and observations were made of sea state, water color, water temperature, salinity, chlorophyll content, cloud cover, and wind speed and direction. Analysis of these data suggested that the turbid waters observed by the crewmembers were actually related to successive passage of pools of brackish Amazon River water.

Hydrology

Hydrological investigations during ASTP included observations and photographs of major river deltas, of snow-cover patterns in the Cascades, and of South American river morphology.

Basically, river deltas are triangular-shaped alluvial deposits formed at the mouths of rivers. In the geologic record, ancient deltaic sediments are often a site of natural gas and oil accumulation, and an understanding of the growth of deltas might have applications in the future development of these resources.

One significant result of the ASTP data analysis was the detection of a probable ancestral delta of the Nile River. The ASTP photographs of northern Egypt revealed an extensive dark-colored and finely textured zone partially overlapped by the present Nile Delta. Extrapolation of the identified zone beyond the ASTP photographic coverage using a false-color Landsat mosaic indicated that this zone forms part of a deltalike pattern and is most probably the late Eocene to early Miocene ancestral delta of the Nile River.

The ASTP photographs of the Fraser, Rhône, Orinoco, Yangtze, and Danube river deltas were also examined. These photographs reveal distinctive suspended sediment patterns that can be related to models of sedimentation in a deltaic environment. The study of these sediment plumes provided information on the short-term processes that dominate deltaic sedimentation—such as river inertia, buoyancy of suspended material, and frictional turbulence.

The ASTP photographs taken over the Amazon and Paraguay river basins showed a remarkable variation in the sizes and morphologies of various rivers. Channel widths, meander wavelengths, and other variables were measured from the photographs and were used to evaluate various empirical formulas for estimating the hydrologic properties of these rivers. This study revealed that these formulas, derived from studies of humid-temperate and semiarid streams, cannot explain the regime behavior of these complex tropical rivers.

The ASTP mission provided an excellent opportunity to observe and photograph snow cover on the Cascades and Olympic Mountains in Washington State. Accurate mapping of snow cover is important in predicting the volume of water reaching drainage systems for use in irrigation and the control of floods. Analysis of the ASTP data revealed that the most accurate snowline determinations were made by using photographs taken with the 250-mm lens. It was found that the availability of color, stereo photographs greatly facilitated interpretations of snowpack distribution, particularly with regard to delineating the very irregular snowline that is characteristic of the summer season.

Meteorology

The ASTP crewmembers were able to observe and photograph a number of interesting cloud patterns. Of special interest were photographs of ring clouds in the Pacific Ocean. Similar circular cloud patterns have previously been defined as atmospheric manifestations of cold-core eddies in the ocean. However, this study found that the features are associated with decaying maritime thunderstorms and are only atmospheric in nature.

CONCLUSIONS

The ASTP Earth Observations and Photography Experiment demonstrated the effectiveness of human observers in studying the Earth from orbit. This effectiveness is not only in verbal descriptions of observed features and phenomena, but in performance of high-quality documentary photography and in instantaneous determination of the most significant objects to study. The degree of effectiveness relies heavily on how well trained and well prepared the observer is.

An obvious feature of the research reports presented in this volume is the variety of the data used. The ASTP photographs from 70-mm and 35-mm cameras were used in conjunction with transcripts of real-time verbal descriptions and postmission debriefings. Also used were photographs from past manned missions such as Gemini, Apollo, and Skylab in addition to images from Landsat and weather satellites. Data from topographic maps, geologic maps, and bathymetric charts were integrated in the reports. Also, information gathered from mission-concurrent investigations such as aircraft photographic flights and oceanic vessel traverses was used. Finally, the data gathered during postmission field trips strengthened, in several cases, the photointerpretations. This variety of data helped establish the utility of spaceborne information in the various fields of study.

The variety of data is also accompanied by a variety in the style of scientific research. Because of the interdisciplinary nature of the experiment team and the data analysis program, most of the papers reflect the personal style of the research conducted. Therefore, some reports are largely descriptive, others are interpretive, and some are model dependent. This variety attests to the great variations in our knowledge of the Earth and to the many ways and means by which scientists attempt to answer questions about its features and phenomena.