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Application of Remote Sensing to Natural Resource and Environmental Problems in Pennsylvania

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Introduction

At the conclusion of the manned lunar program, the National Aeronautics and Space Administration turned its attention to a program of Earth observations from both manned and unmanned satellites with the principal objective of conducting a comprehensive worldwide study of Earth resources and environmental conditions.

The first unmanned satellite in this program was the Earth Resources Technology Satellite (ERTS-1), launched in July 1972, and still operating. It continuously samples a 115-mile-wide swath of the Earth's surface from an altitude of approximately 570 miles with a variety of sensors. Not only does its near-polar orbit enable it to scan the earth from 81°N to 81°S every eighteen days, but also its 103-minute orbit keeps it in pace with the Sun in its daily east-west migration. Repetitive coverage allows observation and systematic monitoring of seasonal temporal changes and transient phenomena such as volcanic eruptions, forest fires, floods, and earthquake damage.

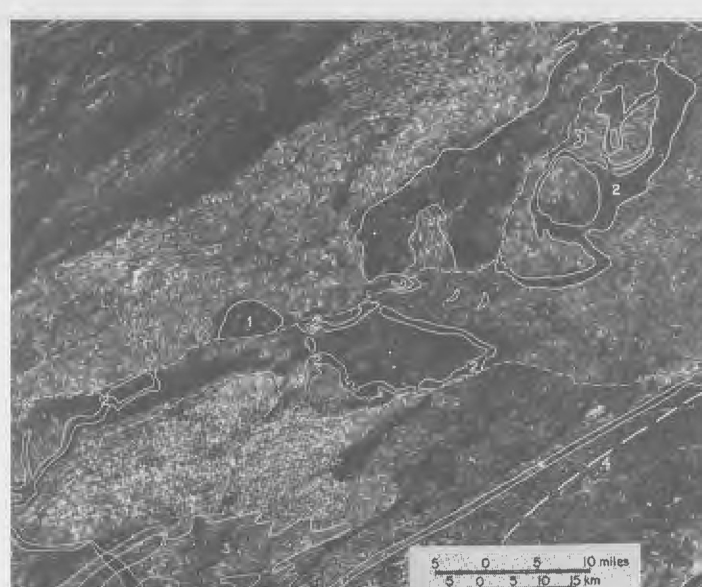
In addition to ERTS-1 and its planned successor, ERTS-B, a manned satellite (Skylab) was launched on May 13, 1973. Selected Earth resources passes similar to ERTS monitoring have been a part of the scientific activities carried out by the astronauts from Skylab.

Workers with diverse technical backgrounds in Penn State's Office for Remote Sensing of Earth Resources (ORSER, a division of the University's Space Science and Engineering Laboratory), including the authors, have been using ERTS-1, Skylab, and lower-altitude aircraft underflight data to investigate a variety of Pennsylvania's resource, land use, and environmental problems.

General Aspects of Remote Sensing

Remote sensing is the ability to acquire information about a phenomenon or object while still at a distance from it. Most commonly, the electromagnetic spectrum is used through either the reflectance characteristics of solar radiation or naturally emitted radiation, such as gamma rays and thermal infrared, that is caused by some internal energy source—for instance, moving ground water that warms or cools the host rock or heat from an oxidizing sulfide ore body. If an artificial source of radiation such as radar or laser beams of controlled wavelength, is focused on the ground, local topography and the thickness of some reflecting surfaces, such as ice, can be determined. Artificial systems are termed "active" in contrast to "passive systems" that use natural solar radiation.

There are still other classes of remotely sensed signals such as the body force fields (gravity and magnetic attractions) and particle motion waves in matter (solid, liquid, and gas) propagated at the speed of sound (seismic



Left, Figure 1. Megalineament map of Pennsylvania, plotted on a mosaic base of channel 7 ERTS-1 images.[6,7] The dashed lines represent known faults that exhibit displacements on this scale. The physiographic provinces—the Allegheny plateau to the north and west, the curved Appalachian folded belt through the central section, and the Piedmont to the southeast—show up well. The dark crescent-like area in the northeast part of the state is the "anthracite coal basin" around Scranton and Wilkes-Barre. Right, Figure 2. ERTS image of an area east of Harrisburg, Pa., with geologic features outlined: (1) Precambrian rocks of the Reading Prong; (2) diabase sills in the Triassic Basin (dashed lines); (3) the Conestoga formation; and (4) the Martic line in the Piedmont.[6,7] (ERTS image 1080-15185-5 10/11/72.)

and acoustic waves). However, remote sensing has come to mean acquiring information via electromagnetic radiation (EMR), using cameras and electronic recording devices such as optical scanners, radar, and thermal infrared sensors operated from aircraft and spacecraft.[1] All of the applications considered here use EMR signals.

Our eyes are remote sensors that use only a small portion (wavelengths between 0.45 and 0.65 microns) of the full electromagnetic spectrum as illustrated in Figure 3-A. Fortunately, the nonvisible portions of this spectrum can be sensed with appropriate artificial detectors (Figure 3-C) and the response transformed into a visual display (as on a television screen) or into printed form (digital or numerical data). Gases such as ozone, water vapor, carbon dioxide, or molecules of air (oxygen and nitrogen), dust, and clouds present in the atmosphere, serve to absorb, scatter, and reflect the incoming radiation so that only about thirty percent of the total reaches the Earth's surface through favorable bands or "windows." These atmospheric windows are shown in Figure 3-B. Note the atmosphere's general transparency to the longer wavelengths and its opacity to short wavelengths.

Different sensors must be used to detect different parts of the EMR spec-

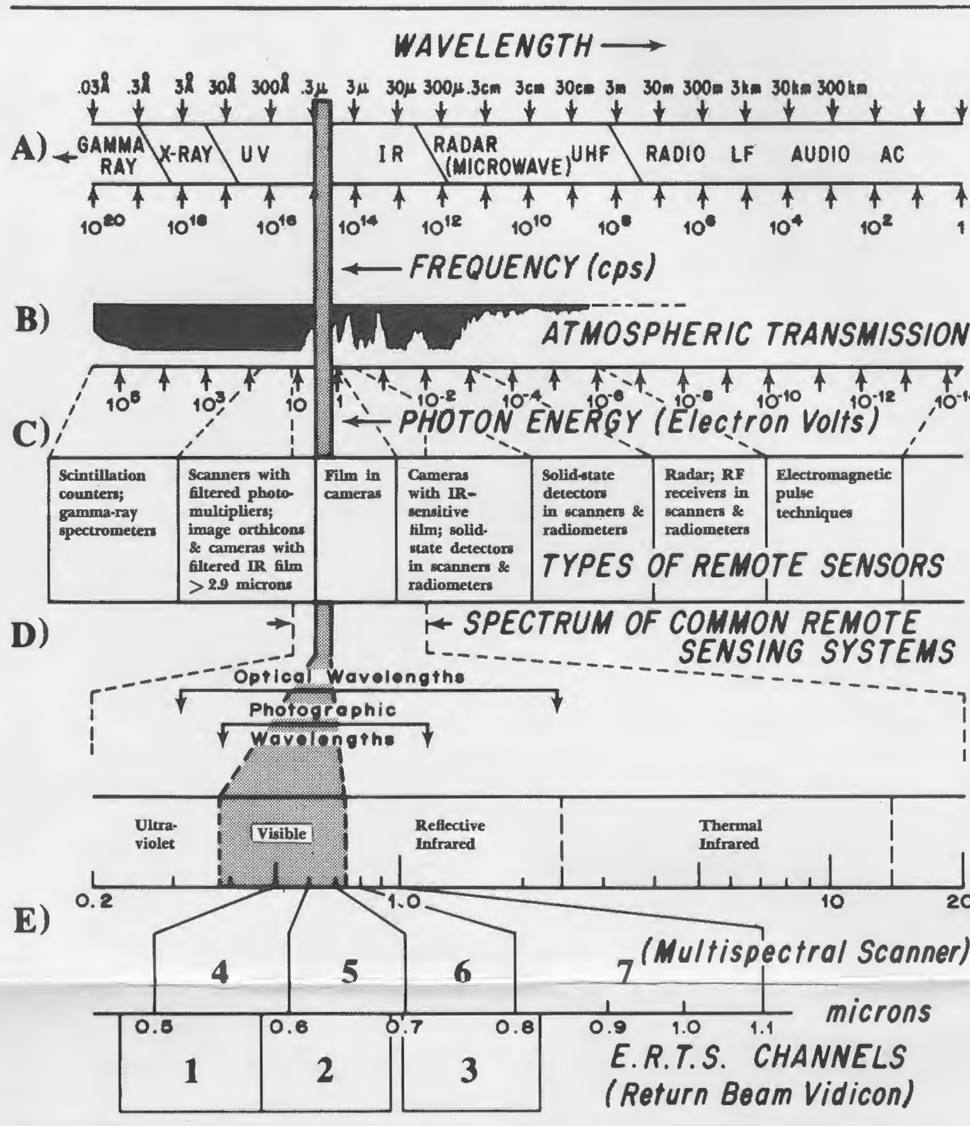


Figure 3. Range of electromagnetic radiation with appropriate detectors and the region of the spectrum pertinent to satellite and airborne sensors. (Compiled from various sources.[1,8])

trum (Figure 3-C). For example, simple cameras have been modified to take not only panoramic views, but also up to sixteen exposures simultaneously of the same area in different wavelengths.

Another important remote sensing technique utilizes an optical-mechanical device in which a rotating mirror scans the terrain in continuous strips transverse to the flight line (Figure 4). The rotation period of the mirror is synchronized with the velocity of the detector platform so that the strips scanned completely cover the area of a swath beneath the detector. Radiation from each area element on the ground (called a pixel) is reflected off the face of a mirror and focused on an appropriate detector. The detector output is amplified electronically and recorded as voltage fluctuations on magnetic tape, intensity-modulated cathode ray tube traces, or a light beam to record directly on film.[2] This is the principle of the scanner. In multi-spectral scanners (MSS), bands of many wave lengths are scanned and recorded simultaneously. On ERTS-1, four discrete scanning sensors operate in the visible part of the electromagnetic spectrum (bands 4, 5, 6, and 7 in Figure 3-E) over a 17-degree sweep angle on the rotating mirror to cover a 115-mile-wide swath of the earth's surface along the flight path. The return beam vidicon camera system (RBV) on ERTS-1, which was designed to take pictures every 25 seconds of an area 115 miles square in three wavebands (Figure 3-E and 4) was switched off after only a few orbits. Because scanner data are distorted only transverse to the flight line rather than radially from the nadir point as in conventional vertical photographs, scan data are preferred for producing orthoimages (maps) as less rectification is needed.

Radiometers and spectrometers are nonimaging devices that measure the intensity of EMR over a given frequency band. Basically, the radiation is split into narrow bands (spectrometers) and wide bands (radiometers) by either a filter wheel, dispersion by a prism or grating, or inferometery and then compared with a calibrated standard (sun-

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TABLE 1. OPTIMUM SCALES AND CORRESPONDING SENSING PLATFORMS FOR MAPPING DEFORMATION AND GEOTECTONIC PHENOMENA*

Structural Scale and Order	Natural Scale and Size of Feature	Types of Phenomena	Types of Maps	Platform and Medium of Observation
Gigascopic 1	1:50 million >1000km	Continental or oceanic plates, seismic plates	Globes; world-wide and continental geologic, tectonic and seismic maps.	Seismic networks (long waves); Various satellites (visible & IR); Space probes; vidiocon, scanner, radiometer (visible, IR & gamma ray)
Megascopic 2	1:1 million 10 km to 1000 km	Mountain belts, basins, island arcs, rift valleys structural provinces, plutons, megalineaments, craters.	Large globes; continental, national, state geologic, tectonic and seismic maps.	ERTS, vidiocon photography & scan imagery (visible & IR); Skylab & intelligence satellites; photography and scan imagery (visible & IR)
Macroscopic 3	1:1000 10 m to 10 km	Folds, faults, lineaments, craters volcanoes, dikes, fracture traces, etc.	Regional, geological and structural maps; fabric diagrams.	Aerial photographs and scan imagery (visible, IR, radar)
Mesoscopic 4	1:1 1 cm to 10 m	Folds, faults, cleavage, joints, bedding, geologic contacts.	Detailed geologic and structural maps; fabric diagrams.	Life-size field work (visible IR, radar, gamma rays) seismic, acoustic, gravity, and magnetic stations
Microscopic 5	1000:1 10 microns to 1 cm	Micro-fractures, deformation lamellae, grain size.	Micro-fabric orientation diagrams.	Microscope (visible, IR, electron, etc.)
Submicroscopic 6	100 million:1 1 angstrom to 10 microns	Lattice defects.	Crystal structure charts.	X-ray, electron microscope

* Larger-scale maps are produced from the higher orders of observation and smaller-scale maps from the lower orders. The arrows on the right indicate the range in scale: (a) up into the unshaded region by synthesis (integration and mosaicing) of the primary observations, and (b) downward into the shaded region by analysis (enlarging and enhancng to the limit of resolution). Compiled from various sources (Ref. 3, 4, 5).

light or an internal source).

Regardless of the detection system employed, the data from the remote sensing platform are returned for processing in the laboratory either manually as film cassettes or magnetic tapes in airborne and Skylab-type systems, or via electronically transmitted signals to the Earth from satellites such as ERTS. These signals are amenable to various types of processing to enhance their usefulness. For example, photograph-like images can be formed; statistical manipulation such as filtering, clustering, and enhancing can be done on a computer; and displays of the radiation intensity in as many as 256 tones of grey scales can be made. Images sensed by any means in different wavelength bands can also be combined, using various filters to produce color composite images in which specific features are emphasized.

Interpretation procedures vary widely depending upon the specific problem being investigated. However, a vital part of any successful interpretation is the correlation of known features on the Earth's surface (ground truth) with the remotely sensed data. The most successful interpretations in remote sensing are those that, by design, involve full use of available ground-based data; however, one of the most difficult aspects of interpretation is casting all the diverse but pertinent information into a tractable form.

One important aspect of remote sensing at different altitudes is that it provides different perspectives of the same feature because the scale of viewing changes. A study of small dimensions involves *analyzing* the subject in progressively finer detail at smaller scales. Conversely, a *synthesis* of data observed in one scale is the vehicle for studying large dimensions. Table 1 represents a merging of terms and an expansion of scale from earlier charts, linking scale and structural phenomena[3,4,5] and also incorporates remote sensing scales and platforms. Clearly, these same scale considerations apply to many other classes of problems that involve spatial relationships. The new remote sensing platforms operating at different altitudes provide coverage on different scales at relatively low cost and effort as summarized in Table 2.

Examples of Geological Applications

Early data obtained from ERTS-1 have been studied by both visual and digital processing techniques to determine the versatility and potential usefulness of this exciting new research tool. Only a few examples are discussed here, but more detailed reports are available concerning these and other applications.[6,7]

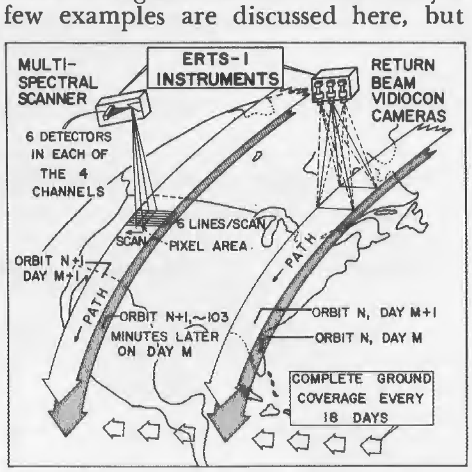

Figure 4. This sketch illustrates the principles of the camera (RBV) and multispectral scanner (MSS) systems on ERTS-1 and the ground coverage pattern. The orbit overlap is greater near the poles than over the equator.

a. Geologic Structures

A mosaic of ERTS-1 images of Pennsylvania was prepared using the first available cloud-free scenes without modification (Figure 1). Physiographic and structural provinces are displayed spectacularly on this mosaic, and the resolution achieved in some images makes possible the tracing of formation contacts for hundreds of kilometers.

Bedrock structures show up well, especially on channel 7 (see Figure 3) in midwinter scenes, even where not accentuated by topography or vegetation. On channel 5 imagery, at a scale of 1:250,000, the contacts of some lithologic boundaries in eastern Pennsylvania (see Figure 2) can be placed with an accuracy of 400 meters (¼ mile or better) with respect to the 1960 Geologic Map of Pennsylvania.[6] The mapping of superimposed structural features such as faults, particularly those along the northern end of the Traissic sedimentary basin near Harrisburg, was disappointing. While the margin of the Reading Prong could be traced from the tonal and land use variations, the geologically mapped faults were not everywhere apparent.[7] Vegetation enhancement over the Triassic diabase sills and dikes made mapping them both simple and accurate. Fracture and drainage patterns and tonal variations serve to distinguish certain rock types but generally little bedrock is sufficiently well exposed to exhibit a direct spectral response. Most contacts are revealed indirectly in the condition and type of overlying soil, vegetation, and land use.

TABLE 2. SUMMARY OF AVAILABLE REMOTE SENSING DATA FOR PENNSYLVANIA AND RELATIVE COST OF ACQUISITION

Platform	Approximate Altitude	Area Sensed in Sq. Mi.	Approximate [a] Scale	Sensor	Coverage of Pennsylvania	Relative Cost of Mosaic of Pennsylvania		
						Frames	Man-years	Cost [e]
ERTS-1	570 mi.	13,275	1:1 million	RBV Camera and MSS	Complete and repetitive	14	1.5	$ 75,000
SKYLAB	310 mi.	10,000	1:700,000	Camera and MSS	Selected areas			
U-2 aircraft	65,000 ft.	320	1:125,000	Camera and MSS	Selected areas			
C-54 aircraft	5000 to 15,000 ft.	1.5-20	1:6000 to 1:44,000	Cameras	Selected areas	938 [c]	11	$ 730,000
C-130 aircraft	5000 to 15,000 ft.	1.4-26	1:6000 to 1:120,000	Cameras and MSS	Selected areas			
Various [b] aircraft	10,000 and 6,000 ft.	7.8 2.8	1:20,000 1:12,000	Camera	Complete, U.S.D.A.; selected areas for engineering studies	20,000 [d]	44	$1,100,000

a. Scale of image on standard 9-inch x 9-inch format; b. standard high and low altitude aerial photographs, sensed in visible light on panchromatic and color film; c. high-altitude aircraft; d. low-altitude aircraft; e. cost based on a 14-frame mosaic of Wyoming (NASA Exhibit).

We are still in the correlation stage so that little new geology has been added to existing geological maps. However, the remarkable correlation between the imaged and the ground truth boundaries demonstrates the feasibility of locating geologic contacts in previously unmapped vegetated areas.

b. Linear Features

Perhaps the most encouraging and unexpected features on the ERTS imagery of Pennsylvania are the number, distribution, and patterns of linear features that can be identified (Figure 1). Geologists have long recognized the presence of straight to slightly curved linear features on the earth's surface. These vary in size from tens to hundreds of feet for "fracture traces" to "lineaments" that are more than a mile in length.

Including ERTS, aircraft underflight, and ground-based data, we now recognize at least six scales of linear features in Pennsylvania; theory suggests[8,9] that the same stress mechanism may explain these features on all scales.

Fracture traces and lineaments may have no direct field expression but are revealed by such features as straight valley segments, abrupt changes in valley alignment, gaps in ridges, gulley development, aligned sink holes and swallow holes, localized springs and diffuse seepage areas, and localized vegetational difference.[10,11]

Fracture traces and lineaments are commonly straight, unaffected by topography, and hence are considered surface manifestations of vertical to near-vertical zones of fracture concentration. On the ERTS images, they appear to be independent of regional structural trends. However, some of the long lineaments, spaced about 10 miles apart, are approximately perpendicular to the Appalachian trend and fan with the bend (orocline) in the Appalachian mountain belt. Offsets and drag features are associated with the east-west striking lineaments, for instance, north of Harrisburg and through the South Mountains near Gettysburg, and represent the surface trace of faults. Except for lineaments coincident with known faults, their physical nature in three dimensions is not known, but, by analogy with the fracture traces, we speculate they are underlain by zones of fractured and jointed rocks, and represent zones of deformation or movement between "jostling" crustal blocks. They transgress rocks from Precambrian to Triassic age in Pennsylvania, and, though they are blanketed by the Pleistocene glacial drift in part of the state, they are not obscured by it. They must be either a rejuvenated crustal fracture system impressed on the younger rocks and in a sense a reflection through the cover rocks of active crustal "joints," or they represent the deformation in response to a widespread and pervasively imposed stress field.[6]

c. Application to Hydrogeologic and Engineering Studies

Drilling tests have established the relationship between the occurrence of ground water and fracture traces for carbonate aquifers, and, in particular, that fracture traces are underlain by zones of localized weathering, increased permeability, and porosity.[12]

Fracture traces could be used to predict zones of increased weathering in advance of foundation exploration; areas of potential roof collapse and excess water in mining and tunneling operations; and leakage beneath dams and into excavations within bedrock.[13] Zones of fracture concentration also account for seepage pressure variation, risk of blowouts and piping, and strength variations within bedrock. Detailed knowledge of the significance and distribution of zones of fracture concentration also is useful in planning, designing, and conducting grout or cutoff wall operations, and in the siting of highly effective pressure and drainage wells; these considerations are important in acid mine drainage abatement projects.

An unexpected density of short and intermediate length lineaments was detected and mapped on the 1:250,000-scale ERTS-1 channel 7 images covering a test area east of Harrisburg. They suggest a scaled-up version of fracture traces. If the lineaments observed overlie fracture zones (as suspected) and prevail to depths corresponding roughly to the same order as their length (as

TABLE 3. SPECTRAL RESPONSES FROM CLUSTER ANALYSIS OF KYLERTOWN AREA

Categories	Number	Symbol [a]	Channels [b]			Percent of Area
			4	5	7	
Forests	1	--	23.43	14.29	24.42	68
Open fields	2	X	27.20	21.37	21.27	17
Trenches (strip mine)	3	+	30.50	25.72	11.00	4
Backfills (strip mine)	4	*	32.89	30.67	14.56	5
Affected by acid mine drainage	5	0	24.67	15.67	14.33	1
New stripping	6	=	38.00	41.00	19.00	1
Cleared for future stripping	7	Z	46.00	52.33	23.67	1

a. Correspond to symbols used in Figure 6; b. numbers for each channel (see Figure 3) represent the reflected energy relative to an internal standard.

implied by theory), then these implications are important to (1) stream and river control and the evolution of landscape, (2) ground-water movement, (3) oil and gas migration and leakage, (4) underground gas storage, and (5) engineering foundation exploration, analysis, and design.

d. Ore Deposits

A most important aspect of the lineament map is its potential application to the location of ore deposits. Using ERTS imagery, close correlation has been observed between metallic ore deposits and the Mount Union-Tyrone lineament in Pennsylvania (Figure 1). Five metallic sulfide deposits are known to be located along this lineament. The bedrock conditions are currently being investigated by ground-based geologic and geophysical methods, and underflight photography along this feature is being analyzed.

e. Strip Mine and Acid Mine Drainage

The objective of this application is to assess the usefulness of ERTS-1 data, particularly multispectral scanner (MSS) data, for (1) monitoring the areal extent of stripping for coal, (2) detecting areas adversely affected by acid mine drainage, and (3) determining the effectiveness of reclamation and abatement procedures of stripped areas.

An area along the West Branch of the Susquehanna River in Clearfield County extending from Karthaus to Philipsburg was chosen for initial tests because it contains old stripped areas, new stripped areas, and numerous examples of acid mine drainage and related effects associated with the mining of bituminous coal in Pennsylvania.[6,7] Supporting detailed ground-based geological and geophysical observations are available for a portion of the area near Kylertown. Aircraft underflight data from U2 and C130 flights are available for portions of the test area as well (Figure 5).

Using a series of computer classification programs developed by members of the ORSER staff,[6,7] ERTS-1 data for this area were analyzed. Not only was it possible to identify stripped areas unambiguously, but additional subclassifications were found to represent real differences in ground conditions, such as trenched areas, recent workings, and the partly vegetated surrounding areas.

The results for a small area around Kylertown are shown in Table 3 and Figure 6. Subdivisions of the stripped areas that were distinctly classified in this test area were: trenched areas, backfills, and new stripping or areas cleared for future stripping operations. Areas of dying or dead vegetation caused by acid drainage from these mines were distinctly classified by cluster analysis and were spatially located correctly. These features could not be

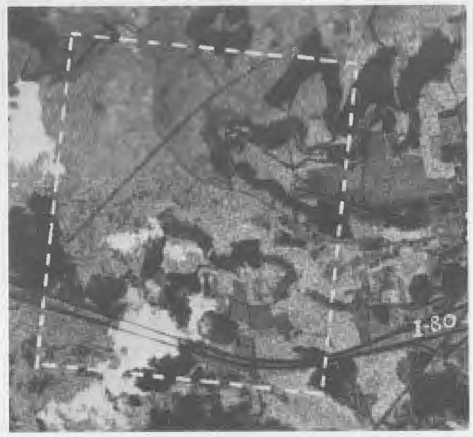

Figure 5. U-2 aerial photograph from 60,000 feet of an area near Kylertown (K). The area covered in Figure 6 is shown in the white outline. Interstate 80 (parallel lanes) also provides a geographic reference for Figure 6.

located by visual analysis of ERTS-1 images.

The digital processing used here has the further advantages that the total area affected by stripping and acid mine drainage is routinely calculated. For example, we found that strip mines cover approximately 20 percent of the test area around the Susquehanna River and about 11 percent of the area around Kylertown. The last column of Table 3 gives the percentage area represented by each category of feature for Kylertown.

ERTS-1 MSS data can be used with appropriate digital-processing programs not only to efficiently map and monitor strip operations on a repetitive basis, but also to detect areas affected by acid mine drainage and to evaluate the effectiveness of reclamation and pollution abatement procedures.

Continuing Research

Work on these and many other applications of remote sensing is continuing through ORSER's research program. Based on results to date and work in progress, we believe that the use of remote sensing information in conjunction with conventional ground-based observations will significantly increase our effectiveness in dealing with many of Pennsylvania's resource and environmental problems at relatively small additional cost.

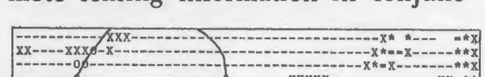

Figure 6. Computer classification map for the Kylertown area[6,7] that is shown in Figure 5. Symbols are defined in Table 3. The area is approximately 3.4 km on a side.

Further details can be obtained through publications and reports available from ORSER, 220 Electrical Engineering West Building, The Pennsylvania State University, University Park, Pa. 16802. However, ORSER is not authorized to provide imagery and digital data to other users; such requests should be directed to EROS Data Center, Sioux Falls, S.D. 57198.

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The Authors

In addition to being members of the Department of Geosciences, the authors are all associated with Penn State's Office of Remote Sensing of Earth Resources (ORSER), an interdisciplinary research program established to apply remote sensing observations to a variety of Pennsylvania problems.

Dr. David P. Gold's interests in remote sensing include the analysis, and size-to-scale-of-observation relationships, of structural features, their tectonic setting and economic implications. Dr. Shelton S. Alexander, head of the geophysics section, is processing digital satellite data into computer printout maps suitable for monitoring such features as coal stripping operations, acid mine drainage damage, and the environmental effects associated with nuclear and conventional power plants. Dr. Richard S. Parizek is assistant director of the Mineral Conservation Section in the college. His remote sensing interests include groundwater occurrence and use of the linear features sensed from flying platforms (satellite and aircraft) to locate new sources of groundwater, floods (Hurricane Agnes), and acid mine drainage problems.

Is Coal Conversion Really Necessary?

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In this time of international concern about energy shortages and increased emphasis on coal as a source of energy, it may well be asked: if oil and natural gas reserves are properly exploited, is there really a need for coal conversion to liquid and gaseous forms? The answer is yes, with some qualifications.

To put the question in proper perspective, it should be noted that this country has enormous hydrocarbon resources. As of December 1973, U.S. crude oil reserves were 34.7 billion barrels with a production of 3.367 billion barrels yearly; gas reserves were 247.31 trillion cubic feet, with a production of 22 trillion cubic feet yearly; and recoverable coal reserves were 1.57 trillion tons (total deposits, 3.2 trillion tons) with a production of 0.595 billion tons yearly. In addition, this country has huge hydrocarbon deposits in the form of oil shale (nearly two trillion barrels), tar sands (25-50 billion barrels), and heavy oil (106 billion barrels). Finally, it should be noted that what is now considered "unrecoverable" oil in the known petroleum reservoirs amounts to 303 billion barrels. This is oil that it has not been economically feasible to exploit.

From these figures, we know that we have roughly a ten-year supply of conventional oil and gas. Thus, if acute gas and oil shortages in the not-too-distant future are to be avoided, coal, oil shale, heavy oil, tar sands, and the so-called "unrecoverable" oil reserves must all be tapped. Of these, coal and the "unrecoverable" oil seem to be the more promising hyrocarbon sources. Shale oil and heavy oil technologies are also being developed rapidly, but tar sands in this country remain a question mark. The deposits here are small, spread over a wide area, and not very rich. However, the hydrocarbon content of tar sands in Canada totals 900 billion barrels, that in Venezuela, 700 billion barrels, and oil recovery from both countries' deposits is currently underway.

It is, of course, well known that there is an oil shortage in the United States and our oil imports are currently approaching 1.5 billion barrels a year—roughly a third of our total consumption. Even more serious—in view of the extreme difficulty of transporting it overseas—is our shortage of natural gas, with supply trailing demand by at least five percent.

Taking these oil and natural gas shortages into consideration, let us consider some of the alternative oil and gas supply sources in relation to coal conversion.

Possible sources of gas are the low-permeability gas reservoirs of New Mexico, Colorado, and Wyoming. Underground nuclear detonations to increase the formation permeability by extensive fracturing have been employed with reported success in New Mexico—Project Gasbuggy—and Western Colorado—Project Rulison. The gas unlocked by each of these projects is estimated at one to two trillion cubic feet, possibly much more.

Two more nuclear detonations in gas reservoirs are planned for the near future. One of these—Project Wagon Wheel—will utilize five 100-kiloton sequential deonations in a Wyoming gas well located in a tight sandstone with the extremely low permeability of 0.0034 millidarcies.

However, a number of serious health and environmental problems remain to be solved before routine nuclear stimulation of low-permeability gas reservoirs becomes a reality. Of the principal radionuclides formed by these nuclear detonations, tritium is of primary concern, most of it being distributed in the form of tritiated water.

The gas from Project Rulison, conducted in September 1969, will be marketed this year at 40-50¢ per thousand cubic feet. It is estimated that the radiation exposure received annually through use of Rulison gas will be about a fifth of that received yearly from watching a color television set. It is not clear, however, what the radiation hazard and the environmental impact would be of the hundred or two nuclear detonations that may be necessary to unlock most of the gas in tight formations in this country.

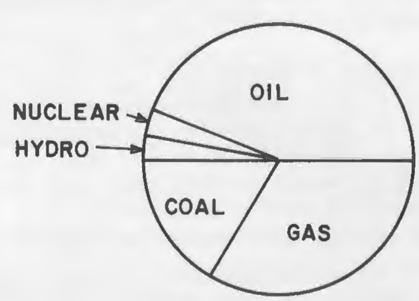
Liquified natural gas (LNG) from abroad could help alleviate our gas shortage. It is estimated that LNG imports will exceed one trillion cubic feet by 1980. However, such gas imports will have to be sufficient to supply a sizable proportion of the year-around consumption, not just seasonal extra demand, in order to be economic.

Furthermore, imported gas is expected to sell at $1.25 per thousand cubic feet, compared to the current average price of 22¢, and very large front-end investments (on the order of $40 billion) in tankers and processing plants will be required. Large LNG imports would, of course, involve dependence on foreign sources which have proved highly unreliable in the case of oil.

In the last couple of years, utilities have turned to substitute natural gas (SNG), which is produced from light petroleum products, as a means of stemming the gas shortage. However, SNG, costing around $1.80 per thousand cubic feet, depends on the reforming of naphtha which is a hard-to-obtain feedstock in view of the current oil shortage. Thus, it is unlikely that many more than the present half dozen SNG plants will be built and those will have to utilize coal as the feedstock.

It should be mentioned that the U.S. is estimated to hold a potential for 1,146 trillion cubic feet of gas and 295 billion barrels of oil yet to be discovered. Most of the gas is expected to be found either in Alaska, offshore, or deeper than 15,000 feet; most of the oil is expected to be offshore. Both will be expensive to recover. This applies, too, for oil and gas from Canada. For example, the transportation cost alone of Canadian gas is projected at 80¢ per thousand cubic feet.

The oil and gas production practices employed in this country are the most advanced in the world and insure the most efficient exploitation of a reservoir possible with existing technology. Nevertheless, our current cumulative oil recovery efficiency is estimated at about thirty percent of the oil originally in place. It is estimated that our recovery efficiency could be improved to thirty-seven percent by 1985. Each one-percent increase is equivalent to more than four billion barrels of oil which are equal in heating value to about 24 trillion cubic feet of gas. However, improved oil recovery methods are ex-



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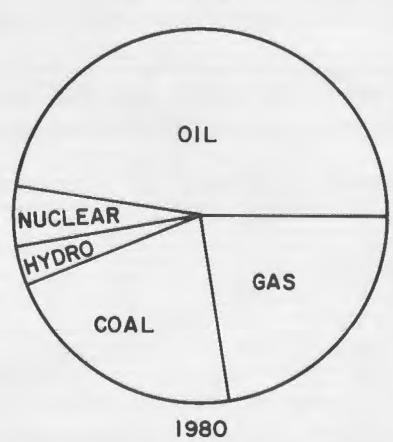


1980

The increasing role of coal in the U.S. energy picture. (After OIL AND GAS JOURNAL*)* pensive, and their large-scale application would require considerable lead time. Furthermore, only one or two of the many improved recovery methods proposed and tested—such as solvents, steam, in-situ combustion, polymers, and surfactants—would be applicable to a given field so that careful screening of the methods to be used would be necessary.

Application of thermal oil recovery methods, utilizing steam or in-situ combustion, has been quite successful in heavy oil reservoirs where the primary oil production was nil. Large-scale development of these techniques has been slow, however, because of marginal economics—a situation that is rapidly changing with rising oil prices. Total oil production by thermal methods is perhaps no more than 70 million barrels annually.

Progress has been even slower in the case of oil shale. The principal problem in this case is not so much the economics as the technology. The feasibility of surface mining and retorting has been proven by pilot plants, but an efficient in-situ oil recovery method must be devěloped if large volumes of shale oil are to be recovered without devastation of the environment. In surface mining, a tremendous amount of earth must be moved to get the shale, and once the oil is removed from it, the waste material left is 25 percent more in volume than the original shale. Despite the optimistic reports that have appeared recently in various mass media, the needed in-situ recovery method is still not around the corner.

In view of the current oil and gas situation and considering the large coal reserves of this country, it is only too natural to conjecture that vast amounts of coal will be converted into gas and possibly hydrocarbon liquids, too. Above-ground coal gasification technology is sufficiently advanced so that significant volumes of gas from coal will be forthcoming in the near future. For example, the Panhandle Eastern Pipe Line Company's Wyoming plant, being built at a cost of $400 million, will supply 250 million cubic feet per day by 1978-80. Also, underground coal gasification technology is currently undergoing a revival and may make it possible to exploit marginal coal deposits. Coal liquefaction is still in the experimental stage with only a few pilot plants constructed so far.

A big hurdle in the development of coal conversion facilities on a commercial basis has been the high product cost. Now this has changed and, with recent increases in the prices of oil and gas, coal conversion processes have become economically much more attractive.

The Author

Dr. S. M. Farouq Ali has been a member of the petroleum and natural gas engineering faculty since 1962. Before coming to Penn State, he worked as a petroleum and mechanical engineer. He has a B.S. in electrical engineering, a B.Sc. in petroleum engineering, and M.S. and Ph.D. degrees in petroleum and natural gas engineering. He has conducted research in miscible displacement, thermal recovery, and simulation of oil production processes and has written more than 90 papers and a book dealing with these areas. Also, he has taught a number of short courses on thermal recovery and reservoir simulation.

E&MS Reprints Available

Recent publications by the faculty of the College of Earth and Mineral Sciences are listed below. Requests for reprints may be addressed to the author whose name appears first (where there is more than one), 5 Mineral Industries Building, University Park, Pa. 16802.

"Skeletal Chemistry of Scleractinian Reef Corals: Uptake of Magnesium from Seawater" by Jon N. Weber; *American Journal of Science*, Vol. 274, January 1974, pp. 84-93.

"Reef Corals and Coral Reefs in the Vicinity of Port Moresby, South Coast of Papua, New Guinea" by Jon N. Weber; *Pacific Science*, 27:4 (1973), pp. 377-390.

"Generic Diversity of Scleractinian Reef Corals in the Central Solomon Islands" by Jon N. Weber; *Pacific Science*, 27:4 (1973), pp. 391-398.

"Average Regional Seismic Hazard Index (ARSHI) in the United States" by B. F. Howell, Jr.; *Geology, Seismicity, and Environmental Impact*, Special Publication of Assoc. of Engineering Geologists, October 1973, pp. 277-385.

"Deep-sea Ahermatypic Scleractinian Corals: Isotopic Composition of the Skeleton" by Jon N. Weber; *Deep-sea Research*, 20: 901-909 (1973).

"Temperature Dependence of Magnesium in Echinoid and Asteroid Skeletal Calcite: A Reinterpretation of Its Significance" by Jon Weber, *Journal of Geology*, 81:543-556 (1973).

New Way to Harness Solar Energy Proposed

If you've ever worn a black shirt on a bright summer day, you know—from the heat you felt on your shoulders—that black can be a veritable sponge for light from the sun.

Dr. Howard Palmer, professor and head of the Fuel Science Section of the Department of Material Sciences, has made use of this principle in developing a preliminary design for a new way of harnessing solar energy.

His "sponge" is graphite, a form of carbon, which soaks up about 90 percent of the visible light that reaches it. In his proposed method for "solar farming," a thin slab of commercial, extruded graphite would be installed inside, and the length of, a long, well-insulated high temperature, alumino-silicate glass pipe through which helium gas would be pumped.

The sun's rays, concentrated by an array of mirrors running parallel to the pipe, would pass into it through a slit in its insulation and strike and be absorbed by the graphite. The energy thus absorbed would then be transferred to the flowing gas by forced convection, raising it to temperatures as high as 1100° F. The mirrors would be movable so that they could be tilted, as venetian blind slats are, to follow the sun throughout the day.

The heated gas from a network (or "farm") of pipes would be capable of driving a closed Brayton-cycle gas turbine coupled to an electric generator. In the closed-cycle turbine, the cool exit gas would be returned through a regenerator and compressor to the pipes for reheating by the sun.

Such a farm of pipes and mirrors, located on a four-by-five-mile parcel of desert, Dr. Palmer estimates, could provide a thousand megawatts of power—enough electricity for a city of 200,000 inhabitants at present rates of consumption. His scheme, he says, is relatively thrifty of land use as well as involving no pollution or waste or use of fuel or water.

No other scheme suggested thus far for large-scale electrical power generation from solar energy takes this "black-solid-to-gas" heat transfer route. Most use molten sodium or "heat pipes" for this purpose and entail, in addition, evacuated piping, exotic optical coatings, heat-storage facilities, extraction of stored heat by water, and a steam turbine to generate power.

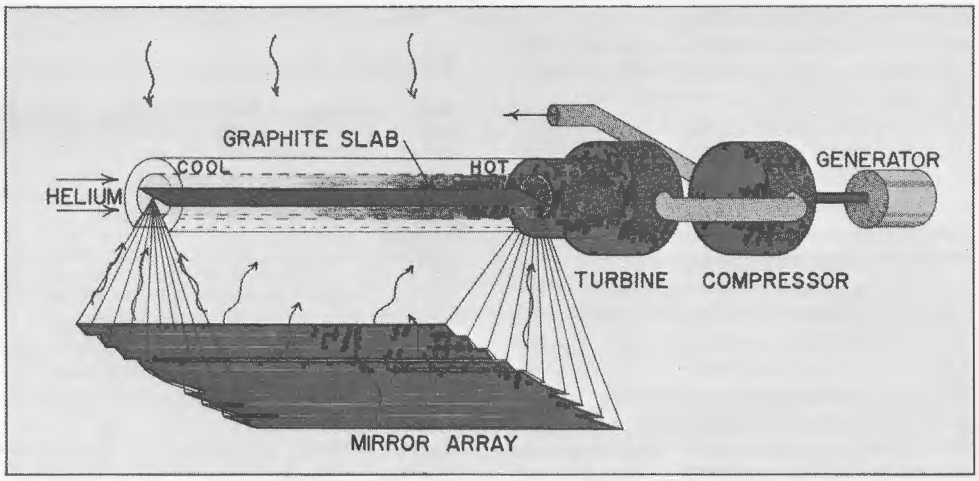
Dr. Palmer's system is much simpler and more direct, due largely to the use of graphite and the gas turbine.

But, naturally, there are complications. "Good mirrors and controls will be required for this system," Dr. Palmer says, "as well as thick insulation for the pipes, and—as for all solar power systems—some provision for energy storage."

He estimates that the "graphite-sponge" technique, combined with the use of a gas turbine, could produce power from the sun at about twice the cost of conventional means. However, now with prospects of increased funding for research, there is real hope, he believes, that efficiency can be improved to the point at which his type of solar farm can become competitive with conventional power.

His system could convert solar energy to electrical energy at an estimated 12 percent efficiency—comparable to efficiencies achieved by other solar-thermal systems. "The relative technological simplicity inherent in the graphite system would, however," he says, "seem to be in its favor."

The fuel scientist envisions solar farms in desert areas or even on man-



Dr. Howard Palmer's scheme for harnessing solar energy is shown in this artist's sketch. The sun's rays, striking an array of mirrors, would be reflected to pass through a glass pipe (through a slit in its insulation), and strike and be absorbed by a thin slab of graphite. Helium gas flowing around the graphite would be heated to drive a turbine coupled to a generator.

made islands located forty to fifty miles off the California coast where there is plenty of direct sunlight most of the year and where electrolytic production of hydrogen from sea water would be very convenient. Energy in the form of electricity generated by the solar farm could enter the electric power grid directly, or could be stored in the form of hydrogen. The hydrogen could be used as a substitute for natural gas and could be piped anywhere in the country.

So far, explorations of the "graphite-sponge" concept have consisted of designs and calculations on paper, plus bench experiments that have established the feasibility of heating gases by this method. Dr. Palmer now plans to model the system on a high-speed computer and scale up the laboratory experiments.

"Working solar farms," he points out, "would enable us to keep fossil fuels for needs such as gasoline, petrochemicals, and polymers, while sunlight would provide much of the electricity we use for lighting, heating, and powering industry.

In developing his scheme, Dr. Palmer has had advice from Simion Kuo, an expert on gas turbines at United Aircraft, and Dr. F. J. Vastola, professor of fuel science, and Dr. G. M. Faeth, associate professor of mechanical engineering at Penn State.

Meeting on Ceramic Materials Deformation

Fundamental principles of the deformation of crystalline ceramic materials and the application of these to the processing of ceramics will be reviewed during the Symposium on the Deformation of Ceramic Materials at University Park Campus, July 17-19.

A continuing education program of the College of Earth and Mineral Sciences, this meeting is being arranged by the Department of Material Sciences.

The program will include four sessions. The first will be a comprehensive review of the concepts of and the measurement of relevant material parameters and properties pertinent to ceramic deformation processes. The remaining sessions will be concerned with single crystal deformation, the deformation of polycrystalline ceramics, and deformation related to forming and consolidation processes.

Further information may be obtained from Dr. Richard C. Bradt or Dr. Richard E. Tressler, Mineral Industries Building, University Park, Pa. 16802.

Burnham Named New Head of Geosciences

Dr. C. Wayne Burnham, professor of geochemistry, has been named head of the Department of Geosciences in the College of Earth and Mineral Sciences.

He succeeds Dr. Arnulf Muan, professor of mineral sciences, who has resumed fulltime teaching and research. Dr. Muan had headed the department since 1971 when it was formed. It includes three sections: geochemistry and mineralogy, geology, and geophysics.

An expert in the area of experimental petrology and the geochemistry of ore deposits, Dr. Burnham has gained international recognition for his research. A member of the faculty since 1955, he was invited by the Australian-American Educational Foundation to lecture throughout Australia in 1970, and served as distinguished lecturer for the Society of Economic Geologists in 1971. Last June, he was invited to visit the U.S.S.R. as a special guest of Russia's Academy of Sciences.

He is currently serving as president of the Geochemical Society, an international scientific organization with more than 1,500 members, and as chairman of the advisory screening committee in geology of the Committee for the International Exchange of Persons (Fulbright-Hays).

A graduate of Pomona College, he received his M.S. in geology and Ph.D. in geochemistry at the California Institute of Technology.

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For descriptive material and information on how to enroll in any of the following continuing education activities of the College of Earth and Mineral Sciences, write to: (Name of Activity), J. Orvis Keller Building, University Park, Pa. 16802.

Elements of Coal Mining Short Course, May 20-22, 1974, University Park.

Coal Characteristics and Coal Conversion Processes Short Course, May 20-24, 1974, University Park.

Pennsylvania Ceramic Association Annual Meeting, June 9-10, 1974, University Park.

Thermal Recovery of Oil Short Course, June 17-21, 1974, University Park.

Particle-size Analysis Short Course, July 16-19, 1974, University Park.

Plastic Deformation of Ceramic Materials Symposium, July 17-19, 1974, University Park.

Reservoir Simulation Short Course, July 22-26, 1974, University Park.

International Union for Crystallography Conference, August 14-16, 1974, University Park.

Longwall-Shortwall Mining Short Course, August 19-21, 1974, University Park.

American Crystallographic Association Conference, August 19-23, 1974, University Park.

Elements of Coal Mining Short Course, August 26-28, 1974, University Park.

Design of Grinding Circuits Short Course, August 27-30, 1974, University Park.

Dam Construction Short Course, September 16-19, 1974, University Park.

Coal Preparation Short Course, October 8-11, 1974, University Park.