Mergers are shown often to produce more than an order of magnitude more rain than isolated clouds on the same day, probably owing to dynamic invigoration of the merged cloud circulations. Results of our first small attempt toward inducing and documenting mergers in a multiple cloud seeding experiment appear promising. Although far from statistically conclusive, they have opened a new frontier in the science and technology of dynamic cloud modification. It is also hoped that the multiple cumulus seeding experiments will help to clarify the formation of "cloud clusters" and their role in large-scale circulations, thus contributing to the focal subject of the Global Atmospheric Research Program in the tropics.

References and Notes

1. W. L. Woodley, *Science* **170**, 127 (1970).
2. The development of silver iodide pyrotechnics was pioneered by P. St. Amand and his colleagues at the Naval Weapons Center, China Lake, California. The flares used in our program have been described by J. Simpson, W. L. Woodley, H. A. Friedman, T. W. Slusher, R. S. Scheffee, and R. L. Steele [*J. Appl. Meteorol.* **9**, 109 (1970)].
3. J. S. Malkus and R. H. Simpson, *Science* **145**, 541 (1964).
4. J. Simpson, *Weather* **22**, 95 (1967).
5. ——— and V. Wiggert, *Mon. Weather Rev.* **97**, 471 (1969).
6. J. Simpson, *J. Atmos. Sci.* **28**, 449 (1971).
7. 1 acre-foot = 1.23×10^3 m^3 = 1.23×10^9 grams of water.
8. The sealed envelopes were kindly prepared by G. F. Cotton of the NOAA Meteorological Statistics Group.
9. The agents were N. Durre and S. Goldweber, for whose fine work and cooperation we are deeply grateful.
10. R. Segman, *NOAA Tech. Memo. ERLTM-AOML*, in preparation.
11. J. Simpson and V. Wiggert, *Mon. Weather Rev.* **99**, 87 (1971).
12. W. L. Woodley, J. Simpson, A. H. Miller, S. MacKay, R. Williamson, G. F. Cotton, *NOAA Tech. Memo. GRLTM-AOML 10* (1970).
13. J. Simpson, W. L. Woodley, A. H. Miller, G. F. Cotton, *J. Appl. Meteorol.*, in press.
14. W. L. Woodley, *ibid.* **9**, 242 (1970).
15. ——— and A. Herndon, *ibid.*, p. 258.
16. The significance tests in Table 1 were performed by G. F. Cotton of the NOAA Meteorological Statistics Group. They are described in detail in the appendix to the report by Woodley *et al.* (*12*).
17. The average rainfall from the 1968 control clouds was 98 acre-feet, less than half the corresponding figure for 1970.
18. 1 nautical mile = 1852 meters; 1 square nautical mile = 3.42 square kilometers.
19. H. Riehl, *Tropical Meteorology* (McGraw-Hill, New York, 1954).
20. R. Ruskin and J. E. Dinger, paper presented at the Interagency Conference on Weather Modification, Virginia Beach, 27 to 30 October 1970.
21. W. L. Woodley and R. N. Powell, *ESSA Tech. Memo. ERLTM-AOML 6* (1970).
22. Global Atmospheric Research Program, Joint Organizing Committee, *GARP Publ. Ser. No. 4* (1970).
23. W. L. Woodley and R. Williamson, *ESSA Tech. Memo. ERLTM-AOML 7* (1970).
24. J. Simpson and W. L. Woodley, paper presented at the Interagency Conference on Weather Modification, Virginia Beach, 27 to 30 October 1970; ———, paper presented at the International Conference on Meteorology, sponsored by the Israel Meteorological Society and the American Meteorological Society, Tel Aviv, Israel, 30 November to 4 December 1970.
25. J. Simpson, R. L. Holle, V. Wiggert, W. L. Woodley, paper presented at International Conference on Tropical Meteorology, Honolulu, Hawaii, 2 to 11 June 1970.

26. We dedicate this article to Myron Tribus whose support helped to save this program. We are also grateful to R. M. White and W. N. Hess in this connection. G. F. Cotton performed most of the statistical analyses, and S. MacKay and R. Williamson did much of the rainfall calculations. A. H. Miller contributed to most phases of the work, as did R. E. Ruskin. We thank the NOAA Research Flight Facility and National Weather Service for their support and the Federal Aviation Administration for fine cooperation. The University of Miami Radar Laboratory ably provided the main data. R. Powell, P. Lewis, S. Johnson, and J. Eden of the Experimental Meteorological Laboratory prepared the manuscript and figures. The work was supported in part by the Office of Atmospheric Water Resources, Bureau of Reclamation, U.S. Department of the Interior, under contract 14-06-W-176.

Archeological Methodology and Remote Sensing

Tests of aerial remote-sensing devices have revealed varying degrees of usefulness to the archeologist.

George J. Gumerman and Thomas R. Lyons

For millions of years man and his ancestors have efficiently utilized their auditory and visual systems as remote-sensing devices for gathering information about the environment. Furthermore, man has probably always realized that his overall perception can be increased by stepping back a few paces and looking from a distance. Remote sensing, then, in the normal sense refers to the acquisition of data from the physical environment by means of a data-gathering system at some distance from the phenomena being investigated. In a much broader sense, remote sensing today encompasses an entire system including data acquisition, data reduction, interpretation, and explanation. The most common mechanical data-acquisition systems are aerial cameras, which utilize various types of film, and the more recently developed scanning devices and radiometers, all of which measure particular wavelength spans within the electromagnetic spectrum.

All materials at temperatures above absolute zero in the natural environment produce electromagnetic radiation in the form of waves. The electromagnetic spectrum is a continuum of natural (passive) and induced (active) radiation in wavelengths varying from fractions of a micrometer to kilometers. There is no single device, including the human eye, which can detect emissions within the entire electromagnetic spectrum, and consequently the spectrum has been somewhat arbitrarily divided into a number of broad categories. These subdivisions range from the very short-wavelength cosmic rays (10^{-16} to 10^{-14} meter) to the very long-wavelength radio waves (10 to 10^5 meters). Between these extremes lie the visible and the near-, intermediate-, and far-infrared portions of the spectrum, which are of particular interest in any data-gathering system applicable to archeological problems.

In an effort to judge for archeological research purposes the imaged output and the correlative value of various aerial remote-sensing devices, the American Southwest was chosen as a major test area. This is an area of vast

Dr. Gumerman is director of the Archaeological Survey and assistant professor of anthropology at Prescott College, Prescott, Arizona. Dr. Lyons is assistant director of the Technical Applications Center, University of New Mexico, Albuquerque, New Mexico, and acting director of the National Park Service Chaco Canyon Research Center.

archeological resources ranging in age from the historic period back to the time of the occupation of the prehistoric Puebloan Indians of 500 B.C. to A.D. 1500 and the big-game hunters of 10,000 to 12,000 years ago. The archeological site, Snaketown, a large prehistoric Indian village of the Hohokam people near the Gila River and 35 miles (56 kilometers) south of Phoenix, Arizona, was the primary test area for the analysis of various cultural features for numerous environmental and archeological reasons. Topographic relief here is no more than 3 meters, and thus the more subtle variations in land form can be most significant in component analysis. Furthermore, this lower Sonoran Desert zone is characterized by sparse ground cover, with the result that a clearer definition of cultural features is more likely than in more heavily vegetated areas. Snaketown has most types of features found at large settlements: habitation areas, trash mounds, extensive irrigation systems, fields, dance platforms, and burial areas. Most of these features are buried, and no stone masonry was used in construction; thus architectural features are difficult to recognize from the air. The site has been partially excavated, and consequently the interpretation of aerial photographs can be verified (*1*). Furthermore, the ancient canal systems of southern Arizona were the focus of some of the first successful attempts at photo interpretation of archeological features in the United States, which demonstrated the applicability of aerial reconnaissance in this region (*2*).

Utilizing Snaketown and other test sites in the Southwest, most notably Chaco Canyon National Monument, New Mexico, we attempted to determine the combination of sensors and sensing techniques best suited for the detection and explication of prehistoric human modifications of the environment.

Black-and-White Photography

Undoubtedly, the most commonly used remote-sensing technique in the visible region of the spectrum is panchromatic photography. Black-and-white aerial photography has been utilized to obtain broader perspectives of archeological remains since the 1890's, and its application to archeology has been documented time and again (*3*). Over this rather extensive period of time, the use of black-and-white aerial photography has not been as extensive as one might have anticipated. However, recent progress in the general field of remote sensing has stimulated interest in the data-gathering potential of aerial photography. In combination with other imagery forms from aircraft and spacecraft, black-and-white photography serves as the standard for the interpretation of archeological and related paleoecological data.

The value of high-quality, black-and-white aerial photography as an aid to archeological reconnaissance cannot be overestimated. In many cases cultural features are as distinct, or even more readily apparent, on black-and-white photographs as they are on the imagery obtained with more recently developed sensors. In addition, the relatively low cost and the large areas of existing coverage in panchromatic photography in many parts of the world make it the most efficient remote sensor for the archeologist.

It is only recently, however, that archeologists have placed methodological emphasis on aerial panchromatic photography (and other sensor systems) as a means for prediction rather than simply as a means for recording and interpretation. For example, a study of the black-and-white aerial photographs of the Estancia Valley in central New Mexico (*4*) clearly reveals the Pleistocene and Holocene beach terraces of several ancient lakes, the waters of which have long since dried up (Fig. 1). This was an area frequented by Paleo-Indian hunters who pursued large game such as the now-extinct mammoths and bison. The predictive value of remotely sensed data was demonstrated by the photomapping of beach terraces, which resulted in the delineation of a large, peninsular area enclosed by three of the major ancient bodies of water. At the time of Paleo-Indian occupation, this was a well-watered area (*5*) and one where game could be driven and restricted in movement, if not trapped or corralled. As a direct consequence of the implications derived from photomapping and interpretation, a survey was made of this area, and several Early Man sites dating back to Folsom and Sandia times were located. Furthermore, relative dating of the succession of old strandlines indicated that the areas fa-

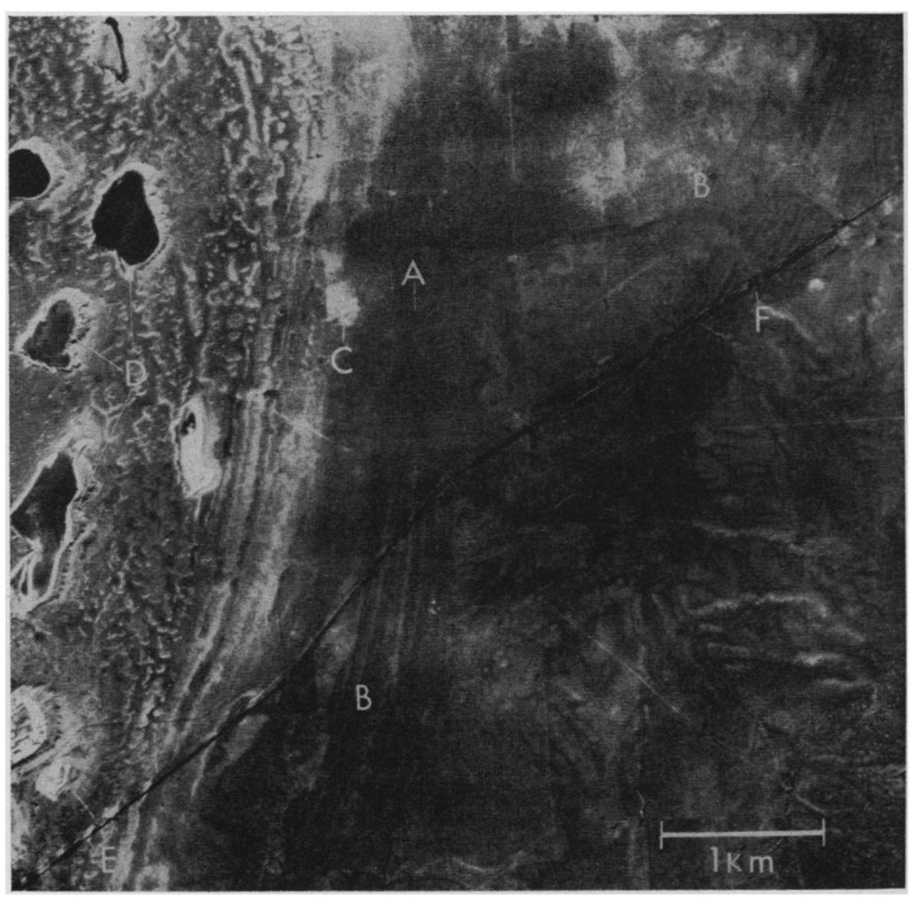

Fig. 1. Black-and-white aerial photograph of ancient beach terraces near Lucy, New Mexico. Mapping of the terraces in terms of a temporal sequence permitted predictions of Early Man sites based on what were once favorable habitation zones. *A*, a Late Pleistocene peninsula; *B*, ancient terraces; *C*, a blowout; *D*, playas; *E*, a highway and railroad; and *F*, Lucy siding.

vorable to the occupation of the early inhabitants were restricted with respect to the temporal distribution of the lakes at different levels within this basin. This knowledge made it possible to predict that the preferred areas of occupation would be located peripheral to adjacent shorelines. Thus, information acquired from black-and-white aerial photographs led to predictions of preferred geomorphological areas of occupation and hunting activity, and these predictions were subsequently confirmed by field surveys (*4*).

Color Aerial Photography

Panchromatic film registers all colors as different shades of gray, with the density of the gray tones indicative of the actual color. True color film registers color similar to that perceived by the human eye and, as a result, offers two more dimensions, that of hue and chroma, over conventional black-and-white photography. Therefore, interpretation of color aerial photographs is enhanced because it is possible to identify objects on the basis of color rather than simply by configuration and gray scale density (*6*).

The advantage of color photography in the Southwest test area seems to lie more in the recording of the natural rather than the cultural landscape. In the Snaketown tests the color film usually revealed cultural features no better than, and in some cases not as well as, the black-and-white photographs, although segments of several small canals were visible only on the color film. Natural features such as vegetation and soil types are more easily distinguished on the color emulsion and, as a result, aid in an understanding of the environmental situation in the area of study. In the Snaketown color photographs, for example, it is possible to determine species of brush and cactus, a determination not always possible in the panchromatic photographs. Thus, ideally, black-and-white photography and color photography furnish complementary information, and features registered on both emulsions can be identified and compared for the extraction of maximum data.

Color aerial film, for all its virtues, has a number of disadvantages for the archeologist when judged by the standard of black-and-white aerial film. Less latitude is allowed the photographer in exposing and processing. If the maximum resolution is to be obtained, considerable care has to be exercised to ensure the correct exposure. Color aerial film is usually produced as transparencies, thus necessitating the use of a light table or highly expensive color reproductions which are difficult to make into satisfactory photomosaics. Also important is the considerably higher cost of both film and processing in the color format.

Fig. 2. Black-and-white rendition of a color infrared photograph of Chetro Ketl ruin. *A*, the ruin; *B*, an old historic road; and *C*, a prehistoric garden area. The left wall of Chetro Ketl and the abandoned historic road are clearer in this figure than on the black-and-white photograph of the Chetro Ketl area (Fig. 3).

Color Infrared Aerial Photography

Unlike true color film which is sensitized to blue, green, and red, color infrared film has three layers sensitized to green, red, and infrared. A yellow filter is used to screen out blue light, which is undesirable for this medium. This film, also referred to as false-color infrared film, camouflage detection film, and infrared Aero Ektachrome film, detects reflected solar radiation at the near end of the electromagnetic spectrum, or slightly into that portion of the spectrum invisible to the human eye. The differential reflection from various cultural and natural features is translated into distinctive "false" colors. For example, alluvium covered by vigorous, nondormant grass will record red, whereas bedrock commonly records blue. Examination of both the Snaketown test area and several other test regions in the Southwest indicates that the principal value of color infrared photography to the archeologist will be not with feature determination by actual color differences, but with tonal contast; that is, cultural features on the Snaketown photographs did not record a different color from that of natural features, but rather the tonal contrasts of a single color revealed cultural components. It is for this reason that black-and-white contact prints of color infrared negatives will usually be as effective, but not as dramatic, as the color transparencies for the archeologist. Black-and-white prints of color infrared negatives register information different from that registered by standard black-and-white infrared photographs, a medium that was not tested as a part of this study.

The phenomenon of tonal contrast is demonstrated in Fig. 2, which is a black-and-white rendition of a color infrared photograph of the region near the ruin of Chetro Ketl in Chaco Canyon, New Mexico. The buried wall on the left side of Chetro Ketl is more readily distinguishable in the black-and-white rendition of the infrared color photograph than it is on the regular black-and-white photograph (Fig. 3), even though color is not used as an identifying factor.

Color infrared photography may also be used in the determination of paleoenvironments, and this technique can be of considerable help in the detection of

Fig. 3. Black-and-white photograph of Chetro Ketl ruin. *A* and *B* are not as clear in this photograph as in Fig. 2; *C*, the prehistoric garden area, is clearer in this photograph than in the color infrared photograph (Fig. 2). In excellent reproductions individual square plots can be recognized that are not apparent in the color infrared film.

Table 1. Various uses of remote-sensing, data-gathering systems applicable to archeological research.

Sensor system	Application										
	Site		Identification of								
	Exploration and identification	Component analysis	Subaqueous site	Rock type	Soil type	Soil moisture	Vegetation type	Vegetation pattern analysis	Plant vigor identification	Geomorphology, topography, limnology	Land use analysis
Black-and-white photography	X	X	X	X	X	X	X	X		X	X
Color photography	X	X	X	X	X	X	X	X		X	X
Black-and-white infrared photography	X	X	X	X	X	X	X	X		X	X
Color infrared photography	X	X	X	X	X	X	X	X	X	X	X
Multispectral photography	X	X	X	X	X	X	X	X	X	X	X
Radar										X	?
Microwave imagery				X	X	?		?		?	X

favorable site locations. The phenomenon of vigorous plant growth appearing in varying shades of red on color infrared film has been utilized by biologists in arid zones in their search for areas of shallow, subsurface waters where formerly a spring issued. In such areas, evidence of the former presence of prehistoric man may be hidden, but the color infrared image, correctly interpreted, can guide the archeologist to previously undetected potential targets.

The disadvantages of color infrared photography are similar to those mentioned for aerial color photography, and there is an even greater problem with correct exposure and film processing. As with the use of ordinary color film, the archeologist will derive the greatest benefit from false-color infrared film if he uses it concurrently with black-and-white film. If photographs of the same subject are made with both types of film, features may be revealed on one emulsion and not on the other, and, as demonstrated in Figs. 2 and 3, in many cases the black-and-white film proves superior (*7*).

Scanner Imagery

A scanner and radiometer can be used to record infrared radiation in the intermediate or far-infrared portion of the spectrum, that is, beyond the practical spectral response of photographic film. The scanner system collects the emitted energy with an oscillating mirror which "scans" the ground surface. The mirror focuses the electromagnetic radiation on a cryogenic detector, which, in turn, converts the radiation to an electrical signal. The signal, which is converted to light, can expose film, be stored on magnetic tape, or be viewed on a television screen. The result is a map of radiation which has a superficial resemblance to a photograph, but which is indeed an infrared image of the scanned phenomena.

The potential usefulness of infrared imagery to archeology consists of the fact that, like color infrared film, buried or obscure cultural features may absorb and radiate solar energy in amounts that differ from that of the surrounding soil matrix, thereby revealing the features on the imagery. A most dramatic demonstration of the archeological effectiveness of infrared imagery is the discovery of prehistoric garden plots in north-central Arizona by their sharp delineation on imagery (*8*). On panchromatic film and on inspection from the surface the plots are invisible or can barely be discerned. The borders of the agricultural plots are enhanced on the imagery because the volcanic ash, which is thicker on the borders, has a lower thermal inertia than the interior of the plots themselves. Additional enhancement may have resulted from the slightly denser growth of desert grasses on the ash borders which absorbed and reflected a different amount of radiation than the surrounding areas.

Another example that illustrates the potential of infrared scanning imagery for recognizing areas favorable for archeological investigation and for the design of field research is the work of the geographer Jean Pouquet (*9*). In his analysis of nighttime radiometer measurements of the Nile Delta area from the satellite Nimbus 1, Pouquet was able to identify different soils of varying ages within the delta for which the relative enrichment or lack of enrichment of organic content was directly related to moisture capture and retention. Maps based on these data were drawn, indicating soils of various ages in an area densely occupied prehistorically. Such pedological differentiations, identifiable because of variable heat flux, are important to the archeologist engaged in the determination of paleoclimatic conditions and other aspects of the paleoenvironment, together with the determination of probable locations of ancient human occupations. Obviously, in terms of research design, relatively older soils would be the anticipated loci for relatively older cultural evidences.

Although the potential of infrared imagery seems great, there are numerous disadvantages associated with its use by archeologists. Scanner imagery does not equal the pictorial quality of photographs, although improved scanners are now being developed. Infrared images also contain some distortion, thus making it impossible to scale distances with desired accuracy. In addition, the infrared images usually do not cover completely the same area as aerial photographs taken simultaneously. This factor complicates the full comparison of photographs and images. The greatest drawback is the limited supply of scanners and the exceedingly high cost of collecting the imagery. At present, the use of scanning systems must be ruled out by the limitation of most archeologists' budgets, except where federal overflight programs coincidentally cover areas of archeological interest. Such federal programs have been conducted in various portions of the United States by the National Aeronautics and Space Administration, and more are planned (*10*).

Many of the aircraft missions in these programs will obtain scanned infrared imagery, as well as imagery from other parts of the spectrum isolated by different types of film and filters (multispectral imagery). These missions will cover large areas which, without doubt, will be of archeological importance.

Sensors operating in bands of the spectrum other than those discussed above have not been applied to archeological problems. Radar and ultraviolet sensors have been tested for data acquisition in earth and biological studies with varying degrees of success; however, the infrared portions of the spectrum have, in general, shown more potential. Archeologists are uniquely dependent upon scientists in other disciplines for advances in methodology; therefore, when ultraviolet scanners receive more attention in the earth sciences, the results may spark archeological interest.

Radar sensors, unlike most other sensors, produce electromagnetic waves and thus radar sensing is an active system with several advantages. Radar imagery can be recorded at any time of the day or night and under any weather conditions. Perhaps most important to the archeologist is the ability of radar sensors to delineate topographic features, particularly in areas having dense forest or virtually continuous cloud cover. Unfortunately, at present, the resolution and pictorial quality of radar output is poor for most archeological purposes. Furthermore, there is a large amount of distortion which makes measurements on the images extremely unreliable.

Remote Sensing and Research Design

In the foregoing, we have emphasized the data-collecting characteristics of remote-sensing systems. However, remote sensing also has much to contribute in support of research design and formulation and testing of hypotheses.

An example of how remotely sensed data can be employed in a problem area in archeology is illustrated by the study of aerial photography of the prehistoric Pueblo communities in Chaco Canyon, New Mexico. Aerial photography clearly shows the magnitude and extent of the ongoing erosion of the canyon walls and indicates the rapidity with which sediments have been deposited on some areas of the canyon floor. These aerial observations, in addition to studies at ground level, have led to the hypothesis that the prehistoric cemeteries, which have never been found in this area, lie buried beneath blankets of rapidly deposited soils. A second and ancillary hypothesis is that during most of the period of occupation parts of the canyon floor were 4 to 8 meters lower than they are today. These hypotheses may be tested in several ways, for example, by large-scale excavation. A photogrammetric interpretation of the volumetric content of soils and fluvial deposits on the floor of the canyon can be made from the aerial imagery. On the basis of this information, the rate of lateral erosion of side canyons and canyon floor aggradation over a known period of time during which the area was occupied by the Chacoans can be quantitatively determined and the validity of the hypotheses can then be determined. The aerial coverage of this region and photogrammetric interpretations are a valuable input to research design for further investigations of the ancient cultures that occupied one of our most spectacular national monuments.

Summary

We have shown that the different spectral surveying techniques and the resultant imagery vary in their applicability to archeological prediction and exploration, but their applications are far broader than we have indicated. Their full potential, to a considerable extent, still remains unexplored.

Table 1 is a chart of the more common sensor systems useful to archeological investigators. Several kinds of photography, thermal infrared imagery, and radar imagery are listed. Checks in various categories of direct and indirect utility in archeological research indicate that the different systems do provide varying degrees of input for studies in these areas. Photography and multispectral photography have the broadest applications in this field.

Standard black-and-white aerial photography generally serves the purposes of archeological exploration and site analysis better than infrared scanner imagery, radar, or color photography. However, the real value of remote-sensing experimentation lies in the utilization of different instruments and in the comparison and correlation of their data output.

It can be stated without doubt that there is no one all-purpose remote-sensing device on which the archeologist can rely that will reveal all evidence of human occupations. Remote-sensing data will not replace the traditional ground-based site survey, but, used judiciously, data gathered from aerial reconnaissance can reveal many cultural features unsuspected from the ground. The spectral properties of sites distinguishable by various types of remote sensors may perhaps be one of their most characteristic features, and yet the meaning of the differential discrimination of features has not been determined for the most part, since such spectral properties are poorly understood at this date.

The difficulty in isolating the causes of acceptable definition in certain portions of the spectrum and the lack of acceptable definition in others suggests that the evaluation of remote-sensing devices discussed in this article is not always applicable to all environmental zones at all times and for all types of cultural features. The uncontrollable variables of terrain, ground cover, weather, types of archeological manifestations, and other factors all play an important role in the utility of the imagery to the archeologist. Factors within the control of the photographer or archeologist, such as altitude, position of the sun, and the direction of flight, can greatly influence the utility of the sensor data. In addition, the variables should not be considered solely as they affect resolution. Resolution, per se, although an important photogrammetric parameter of remote-sensing imagery, is by no means the only important factor in data analysis. The synoptic overview, which is provided by aerial imagery, is frequently as necessary in interpretation as the spotting and identification of individual cultural features. Stated more simply, we might say: "To understand, one most certainly must see the forest as well as the individual trees."

For maximum data retrieval, it is necessary that the archeologist attempt to utilize as many different types of remote-sensing devices under as many variable seasonal and climatic conditions as his resources and skill will allow. Only then he can select the most efficient system for the purpose in his area of study.

References and Notes

1. H. S. Gladwin, E. W. Haury, E. B. Sayles, N. Gladwin, *Excavations at Snaketown: Material Culture* (Medallion Paper No. 25, Gila Pueblo, Globe, Arizona, 1937); E. W. Haury, *Kiva* **31**, 1 (1965).
2. N. M. Judd, *Explor. Fieldwork Smithsonian Inst. 1930 Publ. No. 3111* (1931), pp. 157–166.
3. L. Deuel [*Flights into Yesterday: The Story*

of *Aerial Archaeology* (St. Martin's Press, New York, 1970)] provides a detailed history of aerial remote sensing in archeology.
4. T. R. Lyons, thesis, University of New Mexico (1969).
5. E. Antevs, in *Proc. Phila. Acad. Sci.* **87**, 304 (1935); L. B. Leopold, *Amer. J. Sci.* **249**, 152 (1951).
6. J. T. Smith, Jr., Editor, *Manual of Color Aerial Photography* (American Society of Photogrammetry, Falls Church, Va., 1968).
7. That the individual garden plots near Chetro Ketl (Fig. 3, C) are prehistoric has been demonstrated by the recent excavation of diversion canals to each plot (R. Gwinn Vivian, personal communication).
8. G. G. Schaber and G. J. Gumerman, *Science* **164**, 712 (1969).
9. J. Pouquet, *NASA Tech. Note TND-4603* (1968).
10. "Earth Resources Program Synopsis of Activity" (National Aeronautics and Space Administration Manned Spacecraft Center, Houston, Texas, March 1970).
11. Field work was sponsored by Prescott College and the U.S. Geological Survey, Prescott Research Office. Special thanks go to H. Skibitske of that office. Our gratitude is also extended to W. Meyer, E. W. Haury, J. Judge, and R. Weber.

Scientific Manpower for 1970–1985

The oversupply of Ph.D.'s will seriously affect higher education and national science policy.

Allan M. Cartter

It is a somewhat dubious honor to be invited to give credence to the view that economics is a dismal science. I should hasten to add that economists had little to do with bringing about the conditions which I shall describe, and might have been able to mitigate them had they been given the opportunity. My comments are purely those of an observer with a professional interest and some experience in interpreting trends in the academic labor market.

As early as 1960, Bernard Berelson, in his study of graduate education (*1*), proclaimed that the scarcity of highly trained talents for academic and scientific endeavors was not as critical as was commonly supposed. Despite the multitude of voices attesting to the supposed continuing deterioration in the quality of college teaching faculties—as measured by their formal preparation—and the dire predictions of the National Education Association and the Office of Education (OE), Berelson concluded that "we have a good chance to increase the present rate of doctorates in the classrooms of higher education by 1970, not lower it" (*1*). Since 1964, having been intrigued with Berelson's unpopular view and puzzled by the academic community's unwillingness to view objectively either the present or the future, I have been a somewhat lonely voice trying to convince our university colleagues that most academic fields would have an oversupply of Ph.D.'s beginning about 1970 (*2–4*). Until a year or two ago, despite mounting evidence, the number of converts to this point of view could be counted on the fingers of several hands (*5*). To the credit of AAAS, I should note that Dael Wolfle has long been one of my most sympathetic critics and certainly one of the most astute observers of the scientific manpower scene.

I should confess at the outset, however, that, except for the fields of engineering and the social sciences, I had not anticipated a serious imbalance in the supply and demand of scientists until several years hence, chiefly because my crystal ball in 1964 did not reveal the full fury of Vietnam, the constraints placed upon the federal budget by the war, nor a Republican Administration beginning in 1968. Those events, beyond even an economist's ken, have given me more credence as a prophet than I deserve. The burden of my current message, however, is to stress that we should not attribute today's problems just to a temporary cutback in federal funds for education, research, and development. Even without the topping out of federal support, we would have begun to have an abundance of doctoral scientists in most fields of specialization in the early 1970's, becoming particularly marked later in the decade. The cessation of growth in contract research in universities (indeed, a modest shrinkage in real terms) since 1967 and reductions of R & D, defense, and aerospace expenditures in the nonuniversity sector have brought home to us with a resounding thud what it might have taken another several years to fully comprehend. The conclusion is the same, however: we have created a graduate education and research establishment in American universities that is about 30 to 50 percent larger than we shall effectively use in the 1970's and early 1980's, and the growth process continues in many sectors. The readjustment to the real demands of the next 15 years is bound to be painful.

Before focusing attention upon the scientific disciplines, let me enter a plea for a more informed manpower policy in the future. The experience of the last decade is at best discouraging. Elsewhere I have referred to these years as a period in which we consistently put the blind eye to the telescope (*4*). Like amateur weather forecasters, we have acted as though the best forecast for tomorrow was an exact duplicate of today; thus, while college enrollments were rapidly expanding, we acted as though this rate of growth would continue unabated. It should have been obvious, even to the most uninformed, that this situation could not continue for long and that a day of reckoning would come. The OE is a reasonably good source of information, but traditionally it has been so buried in the process of collecting data that others have had to mine it. Its broad survey of college faculties in the spring of 1962 is a good case in point. Its evidence was dramatic in indicating that, while everyone had thought there was a growing shortage of college teachers, actually the number of teachers with the doctorate degree had climbed more than ten percentage points in the previous decade. This study should have shaken national policy for graduate education to its roots, alerted federal agencies to rethink their expansion policies, and triggered an immediate program of annual manpower samples to verify trends in the critical fields of study.

What did happen? A mimeographed, low-key paper summarizing some tabulations was made available to a few interested researchers several months after the survey was completed. Nearly

The author is chancellor of New York University. This article is based on a speech given at the AAAS meeting in Chicago, 27 December 1970.