14. A. Hewish and S. Okoye, *ibid.* **203**, 171 (1964); *ibid.* **207**, 59 (1965); *see also* I. S. Shklovsky, *Supernovae* (Wiley, New York, 1968), p. 248.
15. M. J. Rees, *Astrophys. Lett.* **2**, 1 (1968).
16. T. Gold, *Nature* **221**, 25 (1969).
17. J. E. Gunn and J. P. Ostriker, *ibid.*, p. 454.
18. This work was partially supported by NASA grant R-09-029-063; R.C.H. was supported by NSF grant GP-11855. The rocket vehicle and vehicle support services were provided by the Sounding Rocket Branch, Goddard Space Flight Center; funding for the attitude control system was provided by NASA. We thank G. Kraft of NASA for directing the preparation of the launch vehicle. We thank D. P. McNutt for advice regarding computer treatment of rocket data tapes.

25 April 1969

Infrared Scanning Images: An Archeological Application

Abstract. *Aerial infrared scanner images of an area near the Little Colorado River in north-central Arizona disclosed the existence of scattered clusters of parallel linear features in the ashfall area of Sunset Crater. The features are not obvious in conventional aerial photographs, and only one cluster could be recognized on the ground. Soil and pollen analyses reveal that they are prehistoric agricultural plots.*

Thermal infrared scanning images of the eastern part of the San Francisco volcanic field about 40 km northeast of Flagstaff, Arizona, were recorded with a Reconofax IV (H.R.B. Singer Co.) infrared scanning radiometer in April, 1966. The radiometer was operated in the 8- to 14-micron region of the spectrum, and flight altitude was 762 m above the ground surface.

The images revealed the presence of linear features which subsequent investigations showed bordered previous unrecognized prehistoric agricultural plots (Fig. 1*a*). The plots are barely visible on black and white aerial photographs (Fig. 2) that were obtained at the same time as the infrared images. Only one of the plots could be recognized by inspection on the ground (Fig. 1*d*).

The agricultural plots are in soil developed in basaltic ash and cinders overlying an upper Pliocene basalt flow. The one cluster of parallel rows recognized on the ground (Fig. 1*d*) consists of parallel ridges of fresh, gray-black, basaltic ash (mean size, 1 mm) alternating with subdued troughs in buff soil derived from weathering of the underlying basaltic cinders and ash. At present, both the ash ridges and intervening soil bands range from 3 to 4 m in width; the present relief of the ash ridges ranges from 5 to 30 cm.

The ash ridges are visibly enhanced [white bands (Fig. 1)] on the infrared images as a result of their lower thermal inertia and relatively higher radiant temperatures during daylight hours (4:00 p.m.). Additional enhancement may have resulted from the slightly denser growth of Upper Sonoran desert grass (tentatively identified as *Bouteloua eriopoda*) on this dark ash unit.

Several kinds of evidence indicate

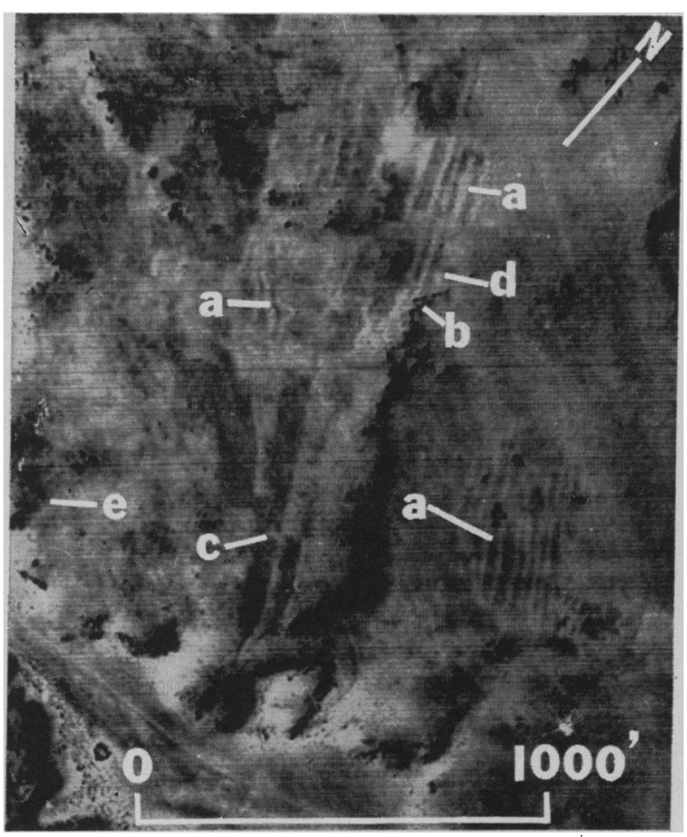

Fig. 1. Infrared scanner image of prehistoric agricultural plots. (*a*) Areas of agricultural activity; (*b*) prehistoric habitation sites; (*c*) wider than normal agricultural plot not recognizable on aerial photograph (Fig. 2); (*d*) area of soil samples 1 and 2; and (*e*) area of soil sample 3 (see Table 1).

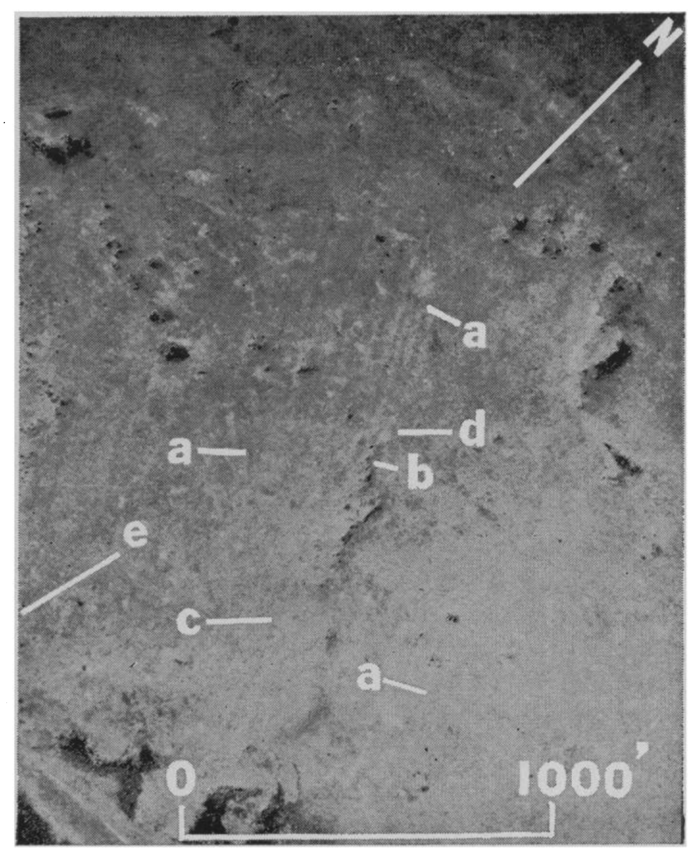

Fig. 2. Aerial photograph (Plus-X) of agricultural plots taken simultaneously with infrared image. (*a*) Areas of agricultural activity; (*b*) prehistoric habitation site; (*c*) region of unique wide farming plots (see Fig. 1). See Fig. 1 for explanation of (*d*) and (*e*).

Table 1. Analyses of soil from prehistoric agricultural community.

Sample No.	Clay content (%)	Total soluble salts (%)	*p*H	Organic carbon (%)	K^+ (ppm)	NO_3 (ppm)	PO_4 (ppm)
1	6.4	0.1045	8.31	1.005	866	2211	56
2	1.8	.1192	8.80	1.162	920	3563	78
3	4.4	.1275	8.65	2.380	812	5237	83

that the alignments are the result of agricultural activity. Analysis of soil samples taken from depths at 5 to 10 cm in the rows between ash ridges (Fig. 1*d*) revealed five grains of maize (*Zea*) pollen in a total of 314 fossil pollen grains (*1*). A sample from the soil beneath an adjacent ash ridge in this area contained a single grain each of maize (*Zea*) and squash (*Curcurbita*) pollen in a total of 323 fossil grains. Soil samples were obtained (i) between the ash ridges in the investigated agricultural plots, (ii) under the ash ridges, and (iii) in an undisturbed control plot about 300 m south of the linear features. Of the three samples, the one from between the ash ridges (sample 1) has the highest clay content, the lowest total soluble salts, and the lowest *p*H, organic carbon, and nutrients. These data indicate an unusual degree of leaching or soil and vegetation disturbance, or both, conditions which would have been brought about by intensive cultivation (Table 1).

Sunset Crater, 22.5 km northeast of Flagstaff, Arizona, erupted in A.D. 1066 or 1067 (*2*), depositing a mantle of black ash and cinder over the area east of the San Francisco Peaks. The pyroclastic mantle, although virtually devoid of plant nutrients in an unweathered state, provided an effective soil cover that absorbed moisture while retarding evaporation. The "apparent" increased soil productivity led to an increase in population due to immigration (*2, 3*).

We found small habitation sites of four and five rooms within several hundred meters of all the linear features in the area shown in Fig. 1, and diagnostic potsherds were recovered from both the dwellings and the agricultural plots. The sherds indicate a Sinagua affiliation and an approximate date range of A.D. 1067 to 1200, that is, later than the eruption of Sunset Crater. The Sinagua, a regional cultural variant centered in the area east of Flagstaff, Arizona, is distinguished by its red or brown utility pottery constructed by the paddle and anvil technique, an extended burial position, and the incorporation of kivas into the dwelling room block.

Parallel borders of boulders outlining agricultural plots have been found at prehistoric and historic southwestern sites (*4, 5*). The Hopis use parallel lines of boulders to anchor brush so that spring winds will not remove the sand cover and damage the young plants (*5*). By analogy, low ash ridges may have provided an anchor for a brush fence, inasmuch as they are at right angles to the prevailing southwest wind; or they may have resulted from attempts to remove ash from areas where it was too deep for the young plants to penetrate the underlying soil.

The evidence from soil and pollen analysis, as well as analogies from historic and prehistoric sites, indicates the utilization of this site for agricultural activity. Thermal infrared images need to be evaluated over different climatic and edaphic zones. Data from the thermal infrared region may usefully supplement conventional aerial photographs (visible and near infrared spectra) which have been utilized in archeological research for a number of years.

GERALD G. SCHABER
U.S. Geological Survey, Flagstaff, Arizona
GEORGE J. GUMERMAN
Center for Anthropological Studies, Prescott College, Prescott, Arizona

References and Notes

1. Pollen and soil analysis was performed by KVL Laboratory, Grand Canyon, Arizona.
2. D. A. Breternitz, *Plateau* **40**, No. 2, 72 (1967).
3. S. H. Maule, *ibid.* **36**, 29 (1963); H. S. Colton, **37**, 77 (1965).
4. R. B. Woodbury, *Soc. Amer. Archaeology Mem. 17* (1961).
5. J. T. Hack, *Pap. Peabody Mus. Amer. Archaeol. Ethnol. Harvard Univ.* **35**, 240 (1942).
6. The remote sensing data were obtained for U.S. Geological Survey by the National Aeronautics and Space Administration as part of the Earth Resources Survey Program under NASA contract No. R-09-020-015. We thank P. S. Bennett of the KVL Laboratory, Grand Canyon, Arizona, for soil and pollen analysis and W. B. McDougall of the Museum of Northern Arizona Research Center for identification of the grass species.

27 January 1969; 14 March 1969

High-Pressure Mechanical Instability in Rocks

Abstract. *At a confining pressure of a few kilobars, deformation of many sedimentary rocks, altered mafic rocks, porous volcanic rocks, and sand is ductile, in that instabilities leading to audible elastic shocks are absent. At pressures of 7 to 10 kilobars, however, unstable faulting and stick-slip in certain of these rocks was observed. This high pressure–low temperature instability might be responsible for earthquakes in deeply buried sedimentary or volcanic sequences.*

Mechanical instabilities are commonplace in solids (*1*) and include buckling of long columns, tensile failure of glass, and Lüders bands in mild steel under tension. For geologic materials, instabilities in compression are of special interest because, if they occur suddenly in the earth, they may be responsible for earthquakes. At a sudden instability, stress drops almost instantaneously, an elastic shock is produced, and elastic energy is radiated from the site of the instability. Although a number of such instabilities have been suggested as the cause of earthquakes, only brittle fracture (*2*) and stick-slip (*3*) have been observed in rocks in the laboratory. We now describe observations of unstable faulting and stick-slip under unexpected conditions and suggest their importance in earthquake studies.

On the basis of many laboratory studies of rock deformation (*4*), confining pressure is generally believed to increase ductility of rocks. In other words, as pressure is increased, the sudden instability associated with brittle fracture disappears and deformation occurs without sudden stress drops. This is not true for all rocks, however, for even at the highest pressures reached thus far (of the order of 11 kb), granite fails violently at room temperature at the strain rates and environmental conditions typical of laboratory experiments (*5*). Two classes of silicate rocks, namely, those that contain a large percentage of weak alteration