Personal Resume - John D. McLaurin

Mr. McLaurin is a Research Civil Engineer in the Branch of Photogrammetry of the Topographic Division, U.S. Geological Survey. He received BSE and MSE degrees in Civil Engineering at the University of Michigan in 1961 and 1965 respectively. He was admitted to candidacy toward a Ph.D in Forestry and Remote Sensing in 1970, also at the University of Michigan. He has spent several years working in the field surveys and photogrammetric phases of topographic mapping with the Geological Survey. In recent years Mr. McLaurin has been conducting research in computational photogrammetry and the applications of remote sensor data to mapping. He is presently working with the cartography discipline of the EROS Program in studying the metric properties of line scanning and television systems and the correlation of multispectral imagery.

APPLICATION OF REMOTE SENSING TO PLANIMETRIC, THEMATIC, AND TOPOGRAPHIC MAPPING

By

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INTRODUCTION

For centuries men have been mapping the earth's surface. The first maps were probably made from estimated distances and directions and from reports of travelers; later, astronomic and field measurements were used. Until about the 1920's, almost all original maps were made with ground surveying techniques. The advent of aerial cameras and photogrammetric plotting instruments produced a significant increase in production, geometric accuracy, and content of topographic maps. However, despite over 50 years of continuous effort, the availability of map data for the world is woefully inadequate. A recent study by the United Nations 1/ has shown the magnitude of the mapping problem with an estimate of the availability of map data. Table 1 is extracted from this study.

Table 1.--Current Status of Topographic Maps

Scale	World	U.S.
1:1,250 - 1:31,680	6.0%	40.5%
1:40,000 - 1:75,000	24.5%	44.7%
1:100,000 - 1:126,720	30.2%	20.8%
1:140,000 - 1:253,440	72.0%	100.0%

Of even more concern is the rate of obsolescence of maps, particularly in urban areas. The rate of obsolescence is increasing and may soon equal the production rate, and therefore with present techniques and capacities the world mapping task will never be completed. In addition, for some maps the production cycle from photography to distribution is from 3 to 4 years, so a map may be as much as 4 years out of date on the day it is published.

Doyle 2/ has summarized the world's mapping needs as follows:

- Complete and revise where necessary the International Map of the World (IMW) at 1:1,000,000 scale.

1/ United Nations, The Status of World Topographic Mapping, World Cartography, Vol. X, 1970.

2/ Doyle, F. J., Mapping Techniques and the World Mapping Problems, paper presented at the Canadian Institute of Surveying Meeting, Halifax, N.S., April 16, 1970.

- Complete and revise where necessary synoptic maps at 1:250,000 scale for the entire world.

- Provide up-to-date medium-scale (1:100,000 or 1:62,500) maps for all settled areas.

- Provide current large-scale (1:25,000 or 1:24,000) maps for all urban, suburban, and cultivated areas.

The capability of revising maps at intervals inversely proportional to their scale is also needed.

Another need is for thematic maps at various scales. These maps depict water areas, wooded areas, cultivated areas, and the massed works of man. Their main use is in locating and measuring natural and man-related features and in monitoring their changes.

To help fill current mapping needs, considerable effort is being devoted to developing new methods for producing and updating maps. For instance, the U.S. Geological Survey is now producing orthophotomaps as a standard product in selected areas. Orthophotomaps contain photoimagery, processed so that the scale is true and uniform, and selected cartographic symbols and labels to enchance important map detail. One of the main advantages of this type of map is that the map production cycle is shortened. In addition, the orthophotomap includes terrain detail that cannot be shown on a standard line map.

Another relatively new technique used by the Geological Survey is interim revision. In this procedure, recent aerial photographs are used to plot cultural and drainage changes which have occurred since the previous survey. The changes are printed on the revised map in purple. Significant cost and time savings result because no fieldwork is required. This technique permits the timely updating of maps.

These new procedures alone will not completely accomplish the world mapping task, however, and cartographers and photogrammetrists are naturally looking for new methods to solve the problem. One of the most promising methods is the use of data from earth-orbiting satellites. Satellites are a logical progression from high-altitude aircraft, and they provide platforms which are inherently global in operation. Analyses and experiments have indicated that space imagery can be used for compiling and revising maps of medium and small scale. Because of its synoptic coverage, space imagery also provides valuable data for thematic mapping because it has no local anomalies in tone as in mosaics of aircraft photographs.

Selection of the Sensor

One of the basic requirements for any sensor to be used for mapping is geometric accuracy. A second requirement is resolution sufficient to identify features to be shown on the map. These requirements follow from the basic purpose of maps, that is, to show the location and extent of features of general interest. In addition to these requirements, thematic mapping requires imagery in selected spectral bands so that signature analysis techniques may be used to separate the features to be shown on the map.

The geometric accuracy requirements are a function of the scale of the map. In the United States these requirements are set by the National Map Accuracy Standards, which for maps of publication scales of 1:20,000 or smaller may be paraphrased as follows:

Horizontal
90% of all well-defined points tested shall be within 0.02 inch (.50mm) of their correct position.

Vertical
90% of all elevations tested shall be within one-half contour interval (with allowance for the permissable horizontal error).

Thus, maps at a scale of 1:250,000 require 90% of the well-defined points to be located within 127 meters of their true position; this corresponds to a standard error of position of 77 m. For a contour interval of 100 meters, 90% of the interpolated elevations should be within 50 m, or a standard error of 32 m.

The National Map Accuracy Standards apply only to the position and elevation of features on the final product--the map. The sensor requirements must be stringent to allow for the inevitable loss of positional accuracy and resolution in producing the map from the sensor image. If the image is used directly to produce a photomap, the loss in horizontal accuracy can be minimized but not completely eliminated.

The sensor resolution requirements are set by factors other than those that affect map accuracy. The main factor is the map content, which is primarily a function of map scale. For instance, 1:24,000-scale maps usually include detail, such as houses, trails, and mines, not normally shown on 1:250,000-scale maps. Consequently, the resolution requirements for a sensor to be used in producing 1:250,000-scale maps are not as stringent as they would be for a sensor to be used in producing 1:24,000-scale maps.

One criterion which can be used to estimate the sensor resolution requirements for producing photomaps is that the resolution of the image at map scale should be just discernible by the eye. A resolution of approximately 10 line pairs per millimeter can be used for the average eye at the usual viewing distance.

Table 2 summarizes the ground resolution and accuracy requirements for various planimetric and topographic map publication scales. These are the basic requirements for any sensors to be used for mapping.

Table 2.--Map Accuracy and Resolution Requirements

Map scale	Std. error of position	Ground resolution	Contour* interval	Std. error of elevation
	meters	meters	meters	meters
1:1,000,000	300	100	500	150
1:250,000	75	25	100	30
1:100,000	30	10	50	15
1:50,000	15	5	25	8
1:25,000	7.5	2.5	10	3

*The contour interval actually used depends on the topography. Average values are used in this table.

For the production of thematic maps, the spectral band of the sensor becomes important. For instance, water bodies are best identified in the near infrared band (0.8 to 1.0 μm) since water reflects very little energy at these wavelengths. Most healthy vegetation, on the other hand, is highly reflective in the near infrared, so this band can also be used for identification of vegetated areas. For the identification of the massed works of man, such as urban areas and transportantion routes, the red band (0.6 to 0.7 μm) is the most useful. In some cases, combinations of bands are required to identify the features to be shown on the thematic map. Thus, the spectral response of the sensors used for thematic mapping should be selected on the basis of features to be mapped. The main requirement is that the spectral bands chosen yield the maximum enhancement of the items of interest.

Thus, sensors to be used for planimetric, topographic, and thematic mapping require good geometry, relatively high resolution, and spectral response which will enhance the features to be mapped. To meet the first requirement, which is important primarily for planimetric and topographic mapping, photogrammetric frame cameras with film to record the image are usually required. However, for small-scale mapping (1:1,000,000) it is possible that high-resolution television systems will be adequate. It is necessary to calibrate TV systems, however, so that the geometric distortions may be removed. Some panoramic cameras and line-scanning systems can meet the resolution or spectral response requirements, but they generally do not have sufficient geometric accuracy for use in mapping. However, increased attention to geometric fidelity could permit these sensors to be used, at least for small-scale mapping.

Collection of the Data

There are at least three basic modes which can be used to acquire imagery for mapping. These are:

1. Aircraft
2. Data transmission from spacecraft
3. Film return from spacecraft

The aircraft mode is the one most widely used at the present time, and it will very likely continue to play a major role in the acquisition of mapping imagery, particularly for large-scale maps. Aircraft are the least expensive platforms when small areas are to be mapped, and they are the best platform to use when the recovery of photographic film is required. However, aircraft platforms have several disadvantages. For example, many photographs are required to cover a large area, and it is very difficult to match tones in mosaicking a large number of photographs. The time and cost of map production vary directly with the number of photographs involved. In figure 1 the number of photographs and control points required to cover an area of 8,700 square km with spacecraft and with aircraft are compared. Another disadvantage of aircraft platforms is that the varying sun angle causes similar features to be enhanced or obscured on different photographs. The wide angle cameras normally used to cover large areas from aircraft can also introduce tonal problems when constructing mosaics.

The second mode is that which is planned for the Earth Resources Technology Satellites (ERTS A and B). This mode relies on a television system or scanner as the sensor, with transmission of the data to the ground by a wide-bandwidth telemetry link. The primary advantage is that the satellite can remain in orbit for a long period of time and provide the potential for repetitive coverage on a global basis. The large amount of data transmitted from the satellite can create a data-handling problem on the ground, however, so the rate of data acquisition must be controlled. The television and scanner sensors do not provide the geometric accuracy and resolution required for large-scale mapping. Small-scale (1:1,000,000) mapping will be possible, however, if sufficient care is taken in calibrating the sensors.

Perhaps the best mode for acquiring imagery for mapping large areas is film return from spacecraft. This mode could use a spacecraft in a relatively low-altitude orbit. After all of the film has been exposed, the film package would be returned to earth for processing. Photographs obtained in this manner could have very high geometric fidelity and resolution, thus being ideally suited for mapping. A study by the U.S. National Academy of Sciences [3/] recommends such a system for mapping.

The sensors proposed by NAS for this system include the following:

- vertical frame camera; 300 mm focal length, 225 × 370 mm format
- vertical frame camera; 150 mm focal length, 225 × 225 mm format
- narrow-angle convergent camera; 600 mm focal length, 225 × 450 mm format
- stellar attitude camera
- laser altimeter

All cameras in this system would provide the necessary ground resolution for mapping at 1:100,000 and 1:50,000 scales, and the 600-mm focal length camera would have sufficient resolution for 1:25,000-scale mapping. This system has been designated by NASA for ERTS C and D, but no approval has yet been given to build these satellites.

3/ National Academy of Sciences, Useful Applications of Earth Oriented Satellites, Geodesy-Cartography, Panel 13, Washington, D.C. 1969.

Of course, the use of film-return satellites assumes the need to map large areas. Because of the high fixed cost of the satellite system, which has been estimated as $15 to $20 million, the cost is the same to acquire photographs of 1000 sq km as it is to acquire photographs of 10×10^6 sq km. The use of a satellite system for mapping can be justified, therefore, only if large areas are to be mapped or repetitive coverage, such as that provided by a data-transmission satellite, is essential.

Regardless of which mode of data acquisition is used, there are two basic sensor calibration requirements which must be considered--geometric and photometric. Geometric calibration is the determination of the changes in image position which result from various imperfections in the sensor. The calibration data are obtained by measuring lens distortion, lens alinement, electronic distortions, and so on, and are used to correct the locations of points on the image so that accurate positions may be determined. In addition, movements of the sensor platform can introduce geometric distortions in the images, particularly for scanning systems, and these must be removed during the image processing.

Photometric calibration is the determination of the response of the imaging element to different levels of illumination. Thus, for a television system, it is necessary to determine how the output signal varies with illumination on different areas of the photosensitive surface, illumination levels, spectral regions, temperature, and so on. Similar considerations apply to photographic systems, although the calibration is more difficult because of inherent nonlinearities in photographic systems. Photometric calibration is important primarily for thematic mapping. It is necessary to know whether a tonal variation on the image is due to changes in sensor response or changes in the ground target so that a correct interpretation can be made.

Most of the available earth-oriented images are photographs taken with hand-held Hasselblad cameras on the Gemini and Apollo missions. Nevertheless, these photographs have been useful for indicating the potential applications of space photographs for mapping. Some results of mapping from these photographs will be presented in the last section of this paper.

Processing of the Image Data

After imagery is acquired for mapping, several procedures must be used to process it into a map. First, the geometric and photometric distortions caused by the sensor must be removed. The techniques for removing distortions vary from relatively simple optical methods to quite sophisticated digital computer processing. A detailed discussion of these techniques is beyond the scope of this workshop, but there is sufficient evidence to indicate that most of these distortions can be minimized.

After distortions are removed, the images must be rectified and scaled to fit a map projection. This usually requires the use of ground control points that are visible on the image and have known coordinates in the map reference system. The most common map reference system is the geographic coordinate system. It is based on an assumed ellipsoidal shape for the earth and datum which defines the location of some initial point on this spheroid. For North America, the figure and datum used are Clarke Spheroid of 1866 and the North American Datum of 1927. Most other areas of the world use the International Ellipsoid.

Because no spherical or ellipsoidal surface can be transformed into a plane without some kind of distortions, several different map projections are used to minimize distortions, depending on the size and shape of the area to be mapped. In the United States, the systems of State plane coordinates based on the transverse Mercator and Lambert conformal conic projections have been widely used in mapping and surveying. These projections, however, vary from State to State and even within States, so problems are encountered when mapping across State or zone boundaries. One system which overcomes most of these problems and can be used worldwide is the Universal Transverse Mercator (UTM) projection and associated grid. This system covers the earth with 60 zones, each of which is 6° in longitude and extends north to 84° latitude and south to 80°. In the polar regions another system can be used--the Universal Polar Stereographic (UPS) projection and grid system. The main advantage of these projections is their worldwide applicability and the availability of tables for their construction.

Regardless of which projection and map reference system is used, the sensor image must be transformed into the selected system. This is normally done by rectifying and scaling the image and superimposing grid intersections. Factors such as earth curvature and terrain elevation must also be considered. Several image correction techniques can be employed, ranging from simple graphical methods to computer-controlled differential rectification.

In the production of photomaps, scaling and rectification are followed by mosaicking and cartographic enhancement. Cartographic enhancement requires the use of auxiliary data to add names, road designations, boundaries, and other information to the map.

For producing thematic maps with imagery of more than one spectral band, registration of the bands becomes important. Each band must be superimposed on the others to within about one resolution element so that the spectral signature of various image points can be determined. Very accurate calibration of the sensors is a prerequisite for good registration. In particular, if separate cameras are used to acquire the imagery, the precision of boresighting, or relative alinement of the optical axes, must be known. The camera lenses should also be matched with respect to focal length and lens distortion. With multispectral scanners, many of these problems are avoided since the same optical system is used for each spectral band.

One technique for automatic thematic mapping now being studied by the U.S. Geological Survey is density slicing. This is a photographic process which isolates very small density ranges on the photographs. Each density range or slice is then printed in a distinctive color, and several slices can be overlaid to produce a composite. One goal is to isolate specific features, such as water, in a unique density range on the photograph so that one density slice can be used as a map of these features. Electronic and optical techniques for automatic thematic mapping are also being studied in an effort to determine which is the most accurate and efficient.

In summary, then, several steps are required to produce a map from sensor images. Figure 2 is a flow diagram of the data-handling concept for earth resource imagery which is being investigated by the U.S. Geological Survey. An image correlator is used to obtain the registration data for several sensor images. A spatial and/or spectral transformation is then done to remove sensor distortions and fit the images to map projection. Fitting the images to a map projection requires the use of ground control and/or orbital data. At this point, planimetric photomaps may be produced. To produce thematic maps, additional processing, either analog or digital, is required. In the analog mode, density slicing or similar techniques are used to identify the signatures of the desired features. In the digital mode, the same process can be performed, but it requires the conversion of the image data into a digital format.

Results and Conclusions

Several studies have been done with the available Gemini and Apollo photographs which indicate some of the potential usefulness of space data. Figure 3 is a color photograph of the Dallas-Ft. Worth, Texas, area taken on the unmanned Apollo 6 mission in 1968. The extent of urbanized area is readily apparent. This photograph was compared with a 1:250,000-scale map prepared in 1954 and updated in 1963 to determine what changes had occurred. Figure 4 shows these changes.

This space photo provided a means of updating the map. If periodic coverage was available, space photos could be used to monitor changes in urban areas.

An example of map revision with space photographs is shown in figure 5. Two photographs taken on the Apollo 9 mission in March 1969 were rectified and overlaid on a 1:250,000-scale map of the Phoenix, Arizona, area. The map was considered current in March 1969, but from figure 5 it can be seen that at least two changes had occurred since the map was made. Figures 6 and 7 show comparisons between the standard line map and the map with a space imagery base. Considerably more detail is visible on the space imagery. The map accuracy was also improved using the space photograph. Figure 8 shows portions of the original map and the corrected map. The map planimetry was moved about 1 mm to conform with the detail on the space photo. This map is for sale by the U.S. Geological Survey.

A second photomap, this one at a scale of 1:500,000, has been prepared from space photographs. Photos from several Gemini and Apollo missions were used in its production. Copies of this map are available from the U.S. Geological Survey for those who would like to make comments on it. The addition of space imagery on the map base holds promise for improving the content, currency, and even the accuracy of conventional line maps or charts.

Several experiments have been done to develop automatic techniques for thematic mapping. Figure 9 shows the results of an experimental effort to extract the surface water distribution from Apollo 9 color infrared photographs. This work was done by RCA, under contract to the U.S. Geological Survey, using an electronic scanning technique.

Figure 10 shows the automatic separation of thick and thin snow areas from an Apollo 9 color infrared photograph. This work was done by Philco-Ford Corporation with photographic techniques. This type of information would be useful to water-supply managers if it were available on a periodic basis.

Other work has been done using photoenhancement techniques to increase the interpretability of the space photographs. For instance, figure 11 shows enchancement on an infrared photograph of the Ouachita River in Arkansas at flood stage. This image provides an excellent view of the extent of flooding. Figure 12 is an enhancement of a selected portion of the photograph used in figure 11. The tone differences in the flooded area are believed to be the result of vegetation on or above water level. Figure 13 shows a photoenhancement of the mouth of the Colorado River. The sedimentation patterns in the water are clearly visible on the enhanced image.

The results of the studies shown in this presentation indicate some of the potential applications of space photography to mapping. The imagery used was certainly not optimum for mapping purposes, and there is considerable room for improvement. The planned ERTS A and B satellites are expected to provide imagery that will be useful for small-scale mapping, both planimetric and thematic. The repetitive coverage capability will certainly be useful for monitoring changing phenomena.

However, to really solve the world mapping problems, other imaging systems will have to be flown. Film-return satellites, as proposed by the National Academy of Sciences, and geosynchronous satellites may have to be used together with aircraft to provide imagery for rapid and efficient mapping operations. Until such systems are in use on a worldwide basis, there is little likelihood that the planimetric and topographic map needs, particularly of the developing countries, will be met.

Glossary

Cartographic Enhancement - The addition of names, boundaries, road and railroad designations and other information to the map base or photoimagery to produce a useable map.

Cartographic Referencing - The scaling, positioning, and gridding of the map information or photoimagery to place it in a map reference system.

Differential Rectification - The process of removing the effects of tilt, relief, and other distortions from imagery by correcting small portions of the imagery independently.

Image Correlator - An electro-mechanical device for locating the corresponding point on two or more images.

Image Enhancement - The manipulation of image density to more easily see certain features of the image.

Map Projection - A systematic drawing of lines on a plane surface using a mathematical transformation to represent the parallels of latitude and the meridians of longitude of the earth or a section of the earth.

Map Revision - Updating, improving and/or correcting map content to reflect the current status of an area.

Mosaicking - The assembling of photographs or other images whose edges are cut and matched to form a continuous photographic representation of a portion of the earth's surface.

Orthophotomap - Maps consisting of photoimagery, which has been processed so that the scale is true and uniform, and certain cartographic symbols and labels which enhance certain map detail.

Planimetric Map - A map which presents only the horizontal positions for features represented.

Rectification - The process of projecting a tilted or oblique photograph onto a horizontal reference plane.

Register - The correct position of one band of a multiband composite image in relation to the other bands or to images collected at a different time.

Resolution - The number of black and white line pairs which can be separately recorded in a dimension of 1 mm. on the image.

Signature Analysis Techniques - Techniques which use the variation in the spectral reflectance or emittance of objects as a method of identifying the objects.

Spectral Band - Portions of the electromagnetic spectrum where the information on a particular image was collected.

Glossary (cont'd)

Synoptic Coverage - Imagery which covers a large area in one frame.

Telemetry Link - The system for transmitting data over long distances using radio techniques.

Thematic Map - A map showing the location and distribution of a certain feature such as water or vegetation.

Topographic Map - A map which represents the horizontal and vertical positions of the features represented.

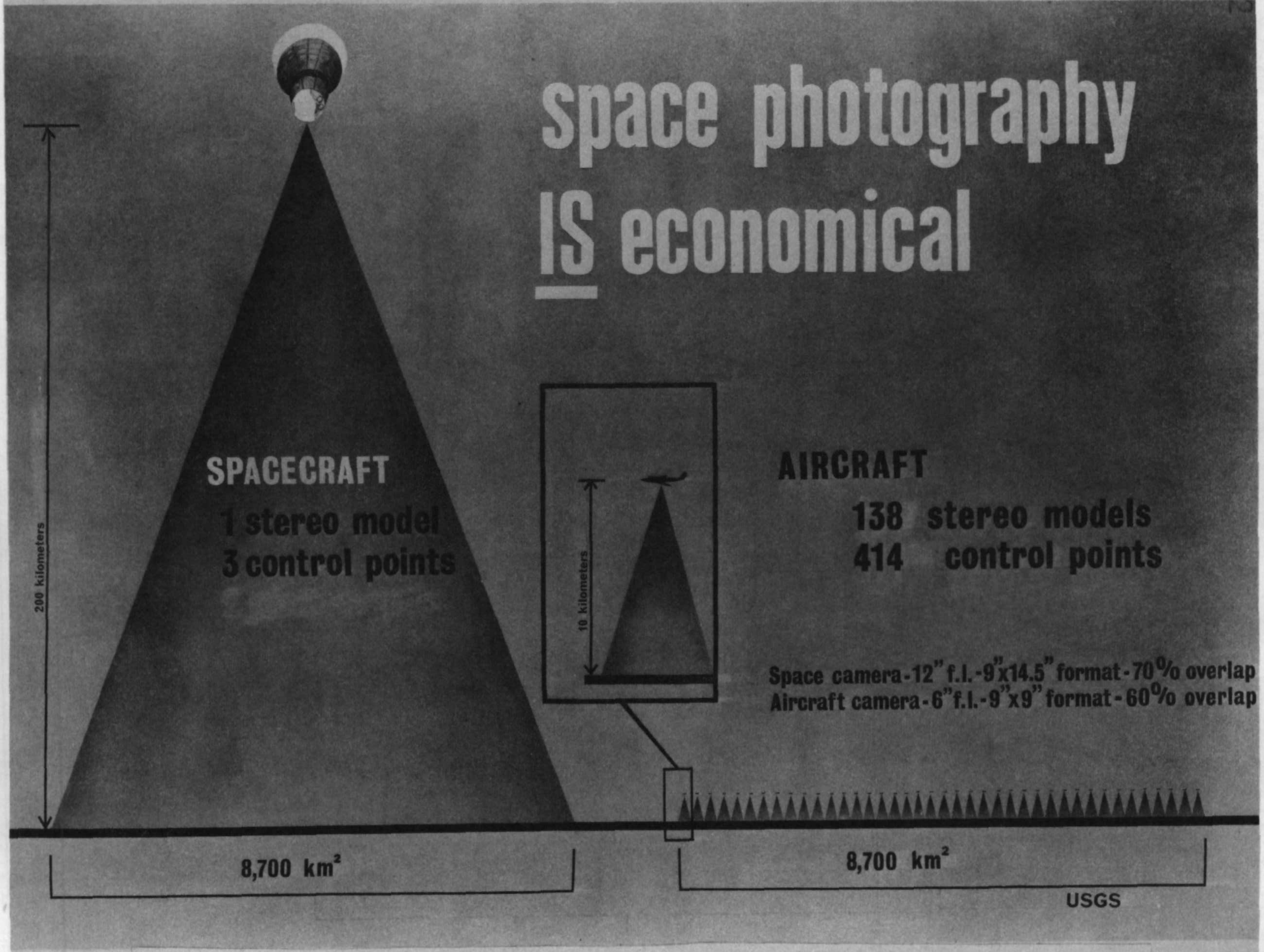


Figure 1.--Comparison of ground coverage of spacecraft and aircraft photographs.

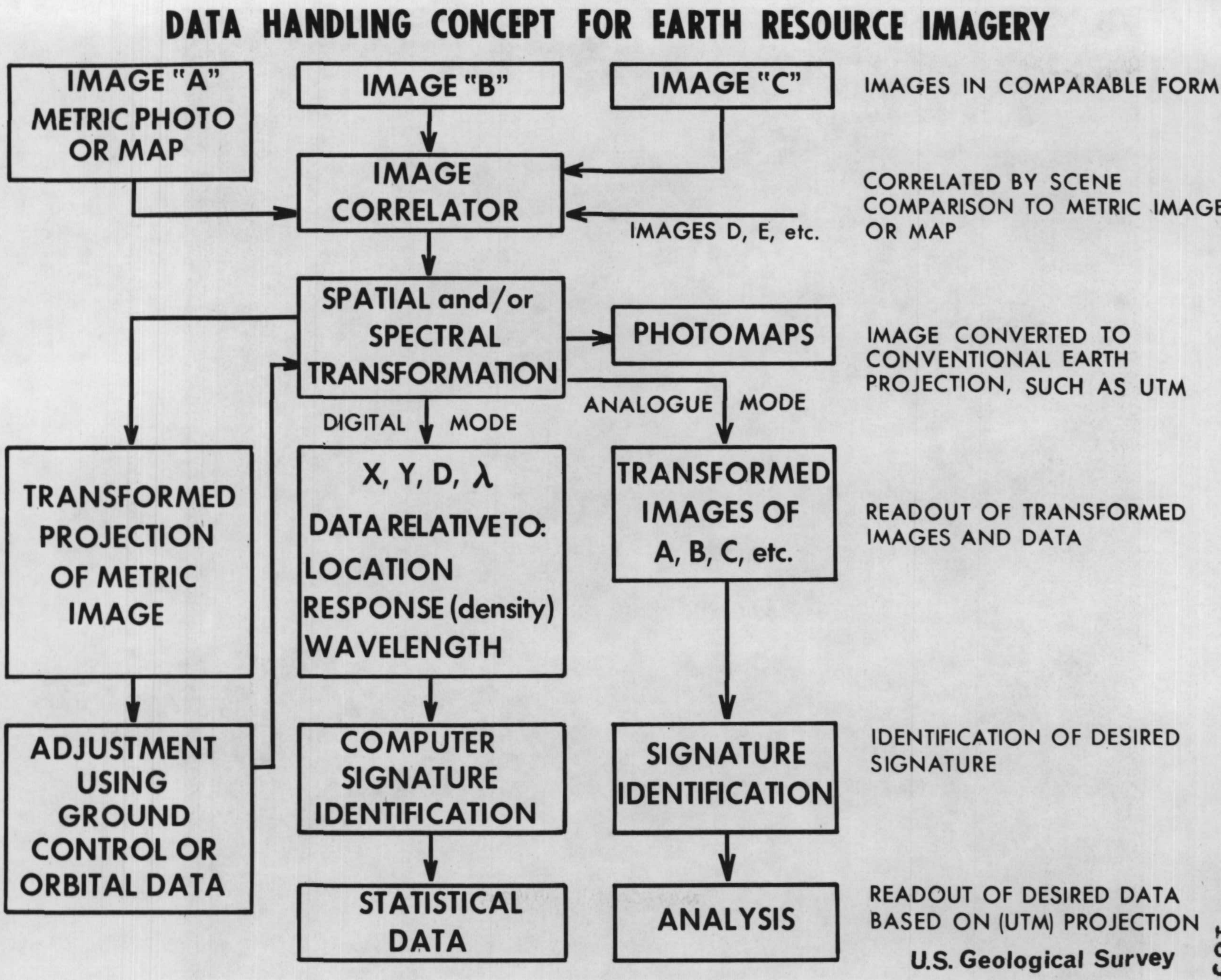

DATA HANDLING CONCEPT FOR EARTH RESOURCE IMAGERY
IMAGE "A" METRIC PHOTO OR MAP
IMAGE "B"
IMAGE "C"
IMAGES IN COMPARABLE FORM
IMAGE CORRELATOR
IMAGES D, E, etc.
CORRELATED BY SCENE COMPARISON TO METRIC IMAGE OR MAP
SPATIAL and/or SPECTRAL TRANSFORMATION
PHOTOMAPS
IMAGE CONVERTED TO CONVENTIONAL EARTH PROJECTION, SUCH AS UTM
DIGITAL MODE
ANALOGUE MODE
TRANSFORMED PROJECTION OF METRIC IMAGE
X, Y, D, λ
DATA RELATIVE TO:
LOCATION
RESPONSE (density)
WAVELENGTH
TRANSFORMED IMAGES OF A, B, C, etc.
READOUT OF TRANSFORMED IMAGES AND DATA
ADJUSTMENT USING GROUND CONTROL OR ORBITAL DATA
COMPUTER SIGNATURE IDENTIFICATION
SIGNATURE IDENTIFICATION
IDENTIFICATION OF DESIRED SIGNATURE
STATISTICAL DATA
ANALYSIS
READOUT OF DESIRED DATA BASED ON (UTM) PROJECTION
U.S. Geological Survey

Figure 2.

Figure 3.--Apollo 6 photograph of the Dallas-Fort Worth, Texas, area.

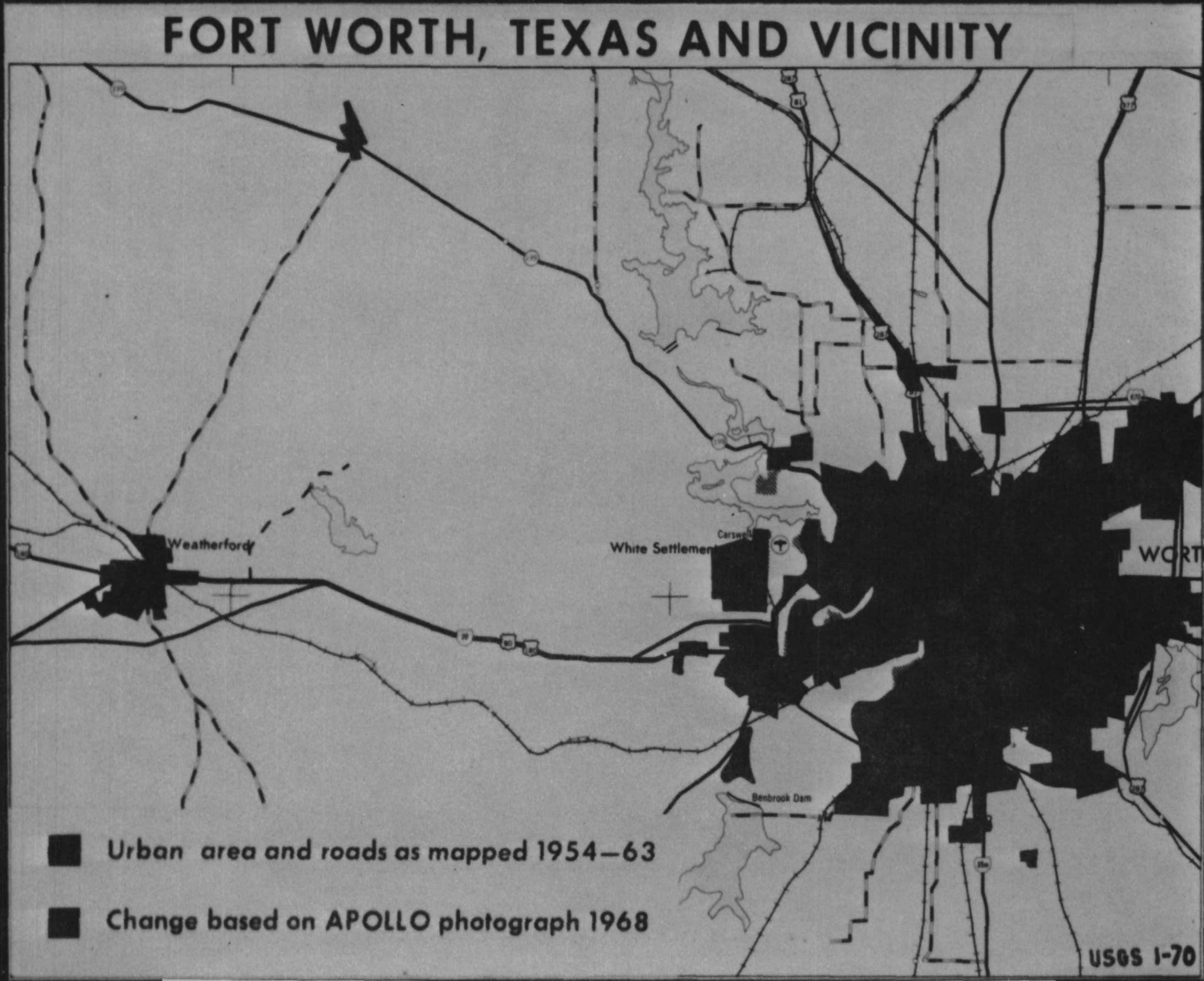


Figure 4.--Revision of the urban area shown on existing map using Apollo 6 photograph.

1969 MANUSCRIPT REVISED BY 1969 SPACE (APOLLO) PHOTOGRAPHY

① **EXTENSION TO INTERSTATE** ② **MISALINED ROAD**

Figure 5.-- the manuscript (1:250,000 scale, Phoenix sheet) was developed by the USGS from all available sources and was considered current as of March, 1969, which is the same date as the Apollo 9 space photograph. On this particular section of the map the space photo indicated both additions and positional corrections to be made to the road net.

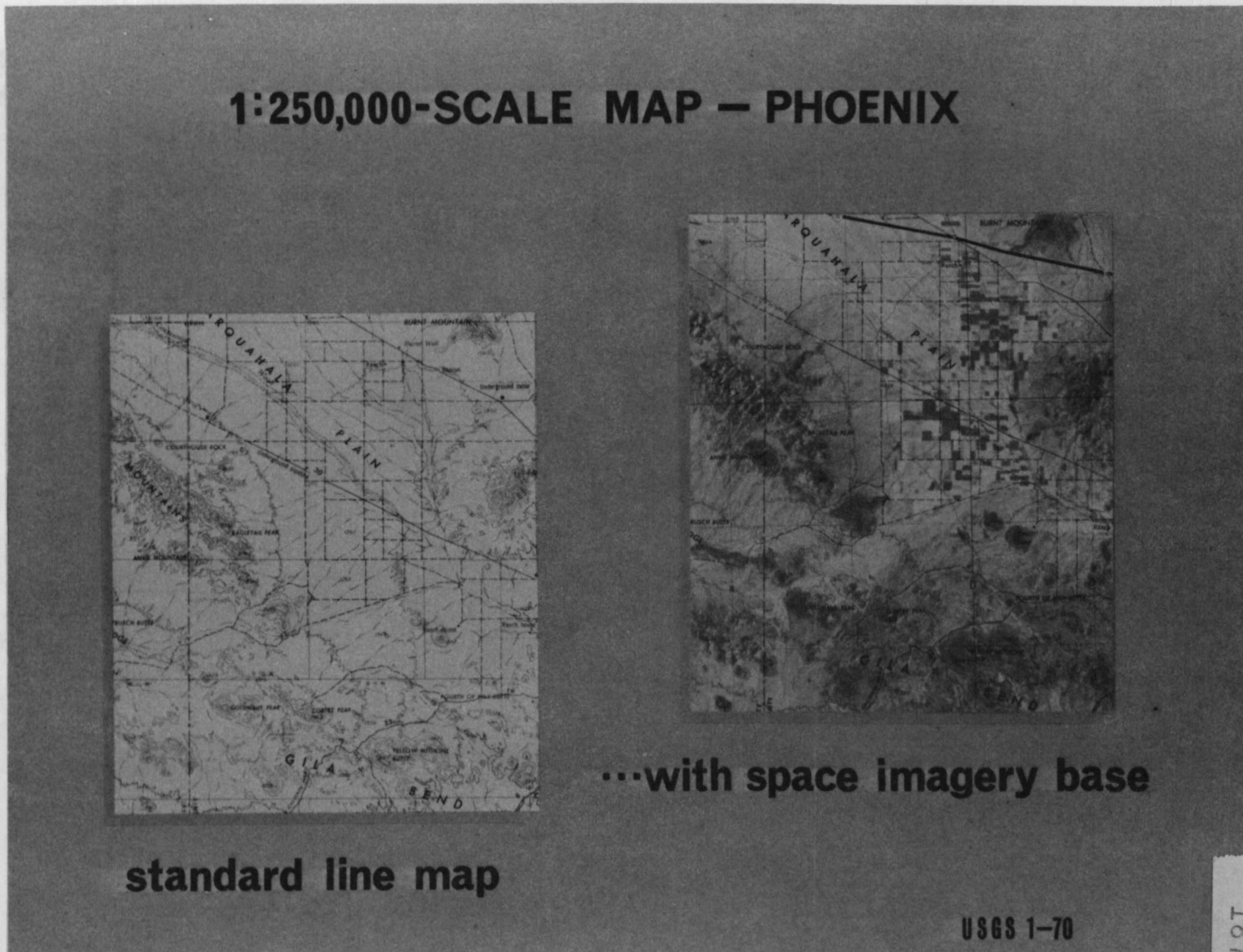


Figure 6.--Comparison of standard line map and map with space imagery base.

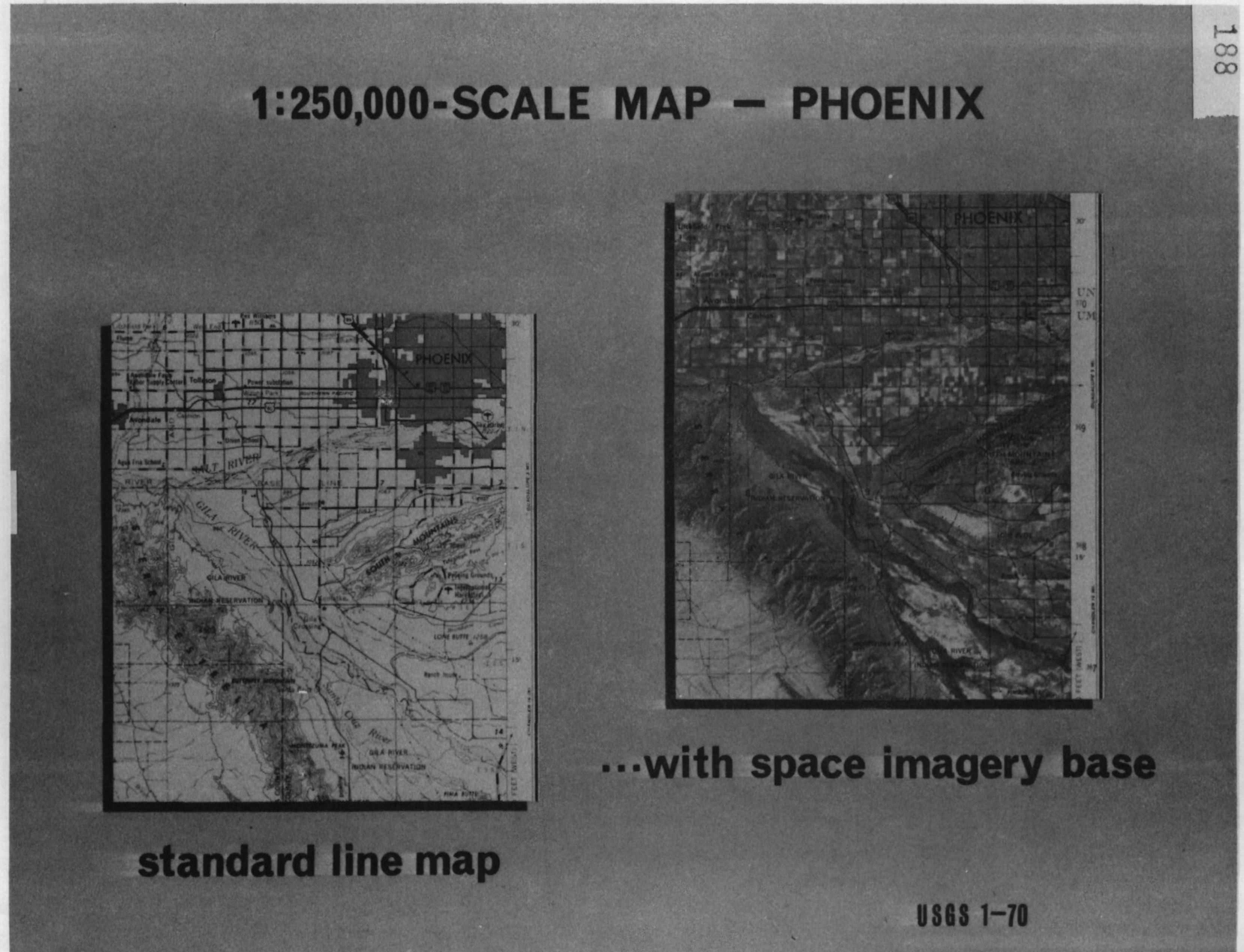
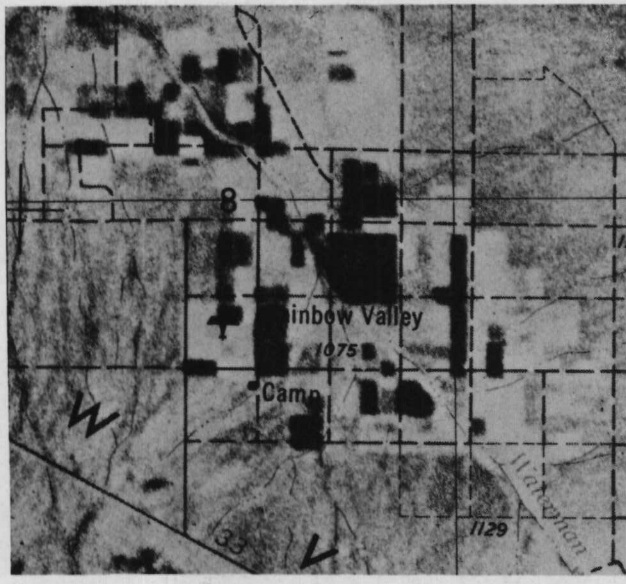
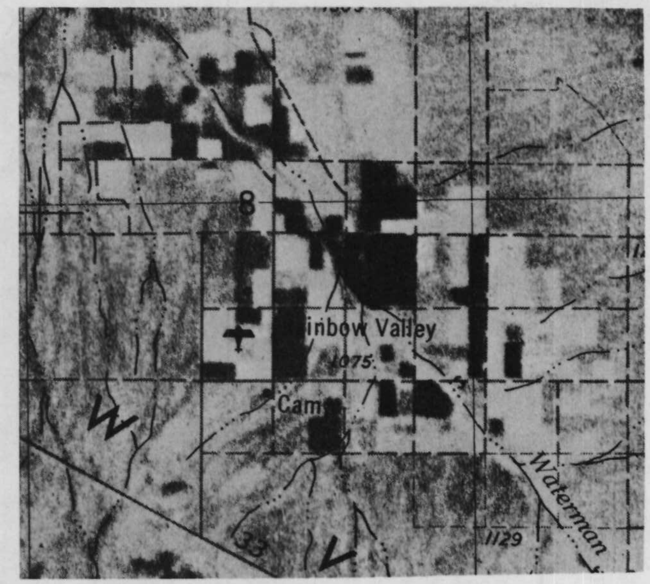


Figure 7.--Comparison of standard line map and map with space imagery base.

Map Accuracy Improved By Space Photo



Original Map



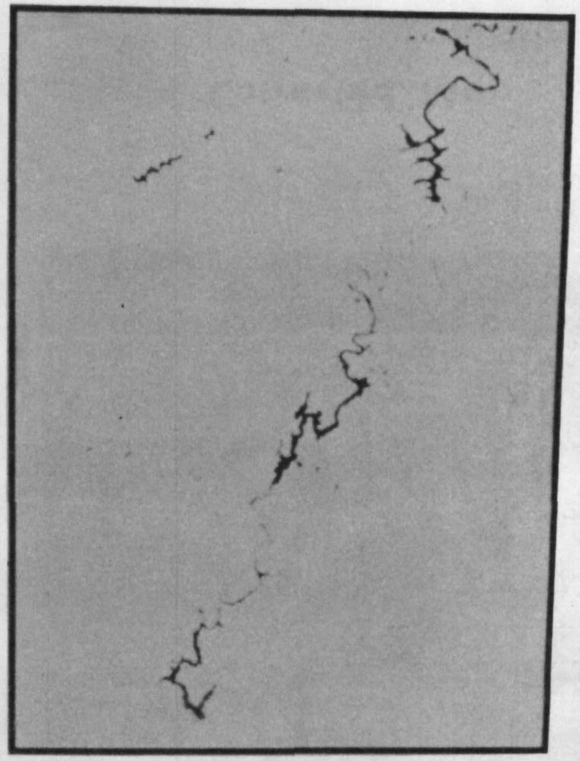
Corrected Map

Figure 8.

Map detail (planimetry) was moved about 1 mm (0.04") on this 1:250,000-scale map (Phoenix) to conform with the detail on the space photo (Apollo 9). The photo was found to be correct.

AUTOMATIC MAPPING OF SURFACE WATER DISTRIBUTION FROM INFRARED SPACE PHOTOGRAPH, ALABAMA

APOLLO SO65 FRAME No. 3790
COLOR I.R
GADSDEN, ALA. AREA



EXTRACTED WATER AREAS
FROM COMPOSITE OF BLUE-GREEN
AND PHOTO IR BANDS

Image enhancement by RCA,
Advanced Video Technology Group

U S Geological Survey

Figure 9.

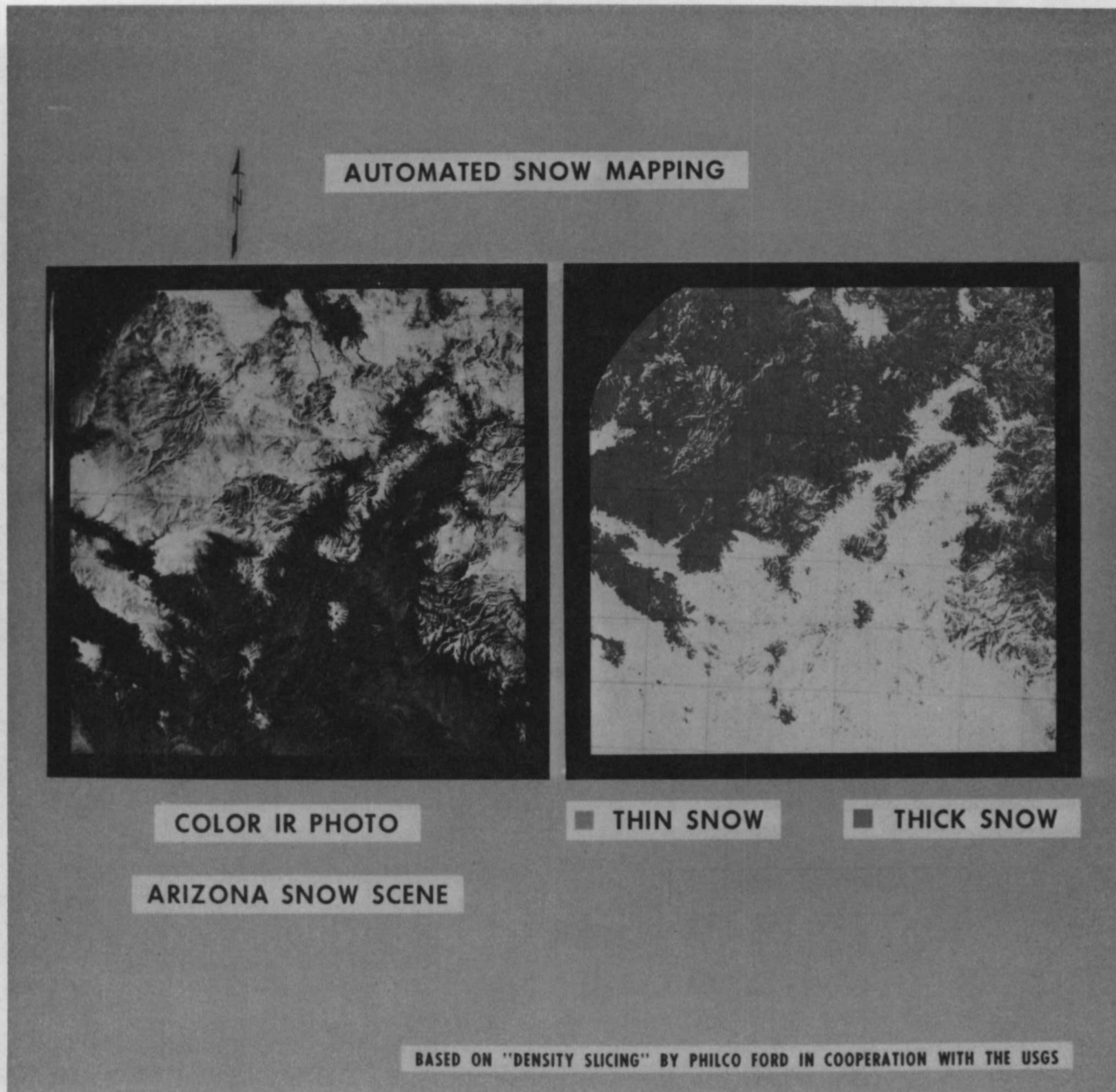


Figure 10.--Extraction of snow information from Apollo 9 space photograph.

Figure 11.--Flood of the Ouachita River as shown on Apollo 9 photograph.

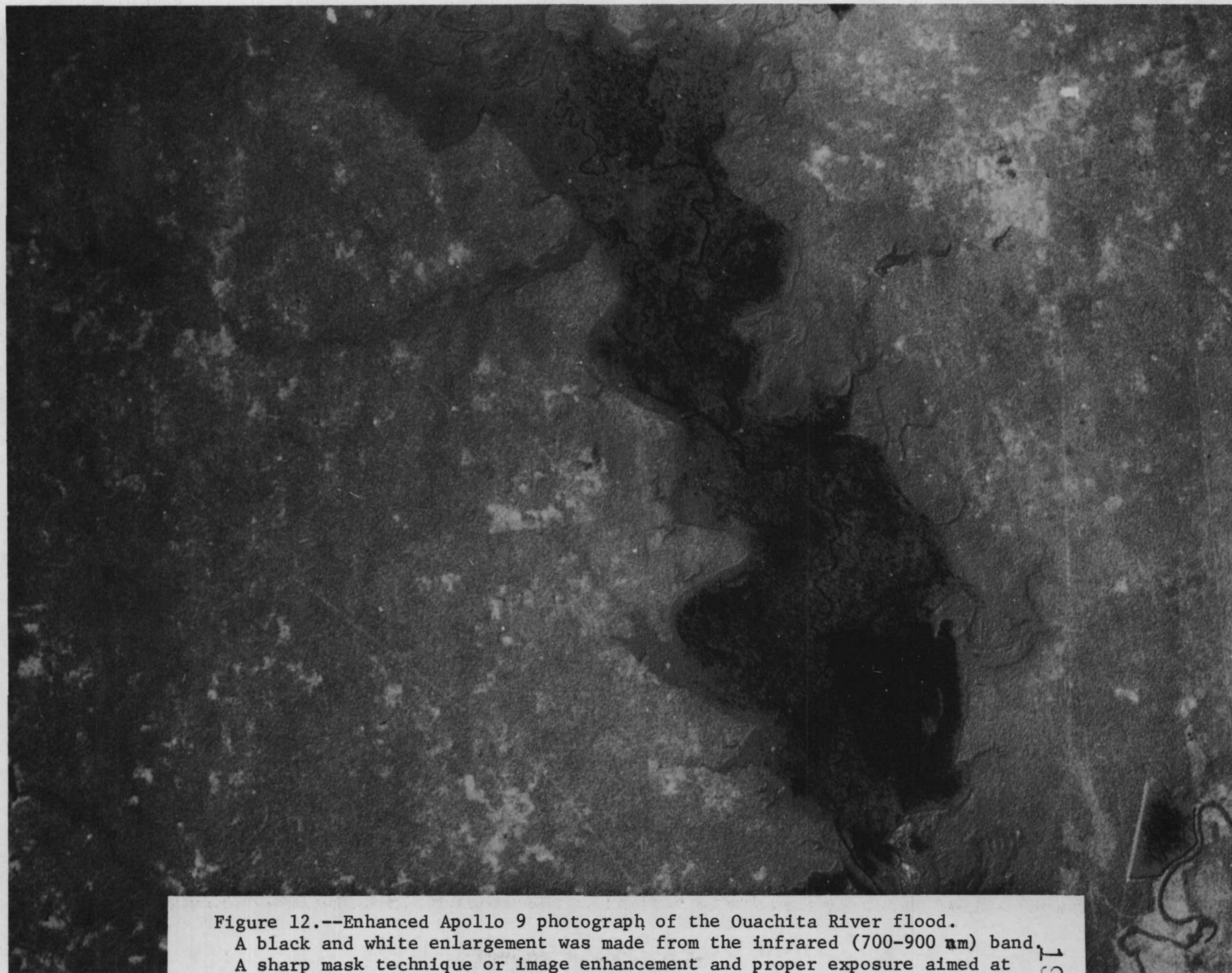
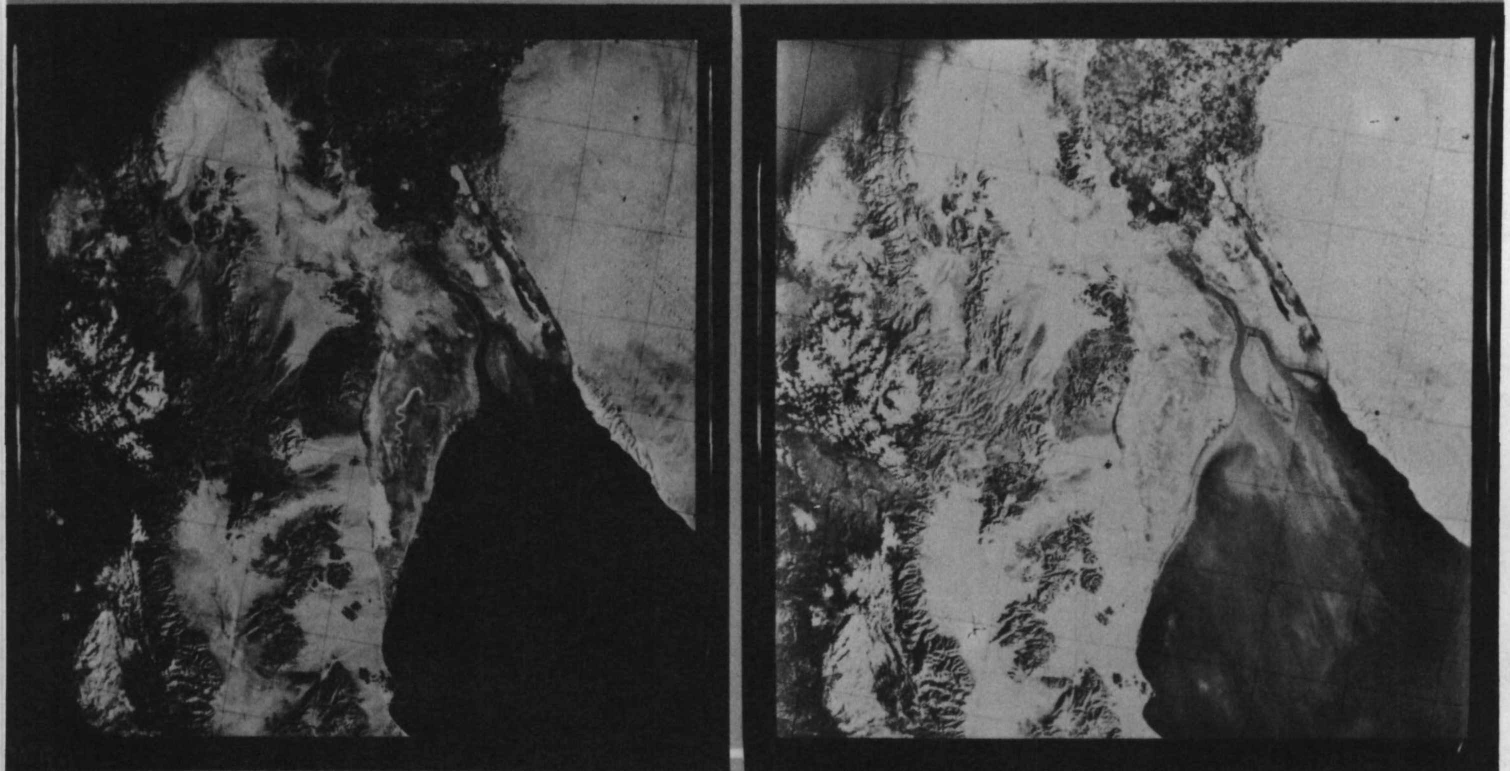


Figure 12.--Enhanced Apollo 9 photograph of the Ouachita River flood. A black and white enlargement was made from the infrared (700-900 nm) band. A sharp mask technique or image enhancement and proper exposure aimed at optimizing density differences were used.

MOUTH OF THE COLORADO RIVER



COLOR IR PHOTO

ENHANCED B&W PRINT OF COLOR IR PHOTO

Enhancement of water detail using conventional photolab procedures

APOLLO 9 PHOTOGRAPH

Figure 13.