Cooperative Studies Between the United States of America and the People's Republic of China on Applications of Remote Sensing to Surveying and Mapping

U.S. GEOLOGICAL SURVEY BULLETIN 2033

Front cover: Image of Beijing resulting from the TM/SPOT merge and enhancement.

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By Donald T. Lauer and Chu Liangcai, Editors

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A report of cooperative investigations between the National Bureau of Surveying and Mapping, People's Republic of China, and the U.S. Geological Survey, U.S. Department of the Interior, United States of America.

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Cooperative Studies Between the United States of America and the People's Republic of China on Applications of Remote Sensing to Surveying and Mapping

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Abstract

A Protocol established between the National Bureau of Surveying and Mapping, People's Republic of China (PRC) and the U.S. Geological Survey, United States of America (US), resulted in the exchange of scientific personnel, technical training, and exploration of the processing of remotely sensed data. These activities were directed toward the application of remotely sensed data to surveying and mapping. Data were processed and various products were generated for the Black Hills area in the US and the Ningxiang area of the PRC. The results of these investigations defined applicable processes in the creation of satellite image maps, land use maps, and the use of ancillary data for further map enhancements.

INTRODUCTION

This report describes the activities and accomplishments of the scientific and technical exchange between the National Bureau of Surveying and Mapping (NBSM), People's Republic of China (PRC), and the U.S. Geological Survey (USGS), U.S. Department of the Interior, United States of America (US), under Annex III of the Protocol for Scientific and Technical Cooperation in Surveying and Mapping Studies.

On April 16, 1985, officials of the governments of the USA and the PRC signed the Protocol to promote cooperation in photogrammetry, remote sensing, cartography, geographic information systems (GIS), and other studies of surveying and mapping. The Protocol specified that cooperative activities must include (1)the exchange of scientific and technical information through scientists, specialists, technical consultants, and delegations; (2)research on subjects of mutual interest including the design and installation of instruments and equipment; (3)the exchange of technical results and other materials considered appropriate and necessary for the cooperative effort; (4)the joint organization of scientific conferences, symposia, and lectures, or attendance at meetings; and (5)other forms of cooperative activities that are mutually agreed upon.

The USGS was assigned the responsibility for coordinating the participation of the US in the joint program. The NBSM of the PRC was assigned a similar responsibility for Chinese participation. To administer the cooperative activities, a Joint Working Group was established. Each country designated a cochairperson to lead the Joint Working Group. These individuals consulted with each other on a regular basis to review and plan cooperative activities and to perform other related duties. The Joint Working Group met periodically to review completed work and work in progress and to plan future cooperation.

Scientific and technical cooperation to promote the development of remote sensing techniques and their application to surveying and mapping is defined in Annex III of the Protocol. Objectives in Annex III include (1)the development of techniques for geometric and radiometric rectification of remotely sensed data; (2)the application of remotely sensed data to map revision; (3)applications of remotely sensed data to thematic mapping using enhancement and classification techniques; and (4)the integration of remotely sensed data from various sources with other types of data for land use mapping and related applications.

BACKGROUND

To carry out the objectives of Annex III, remotely sensed and ancillary data collected over study sites within each country were used. The NBSM chose the Ningxiang area in Hunan Province, and the USGS selected the Black Hills area in the State of South Dakota. These sites were selected because preliminary experimental work already had been completed and aerial photographs were available or soon would be. Both countries immediately began to acquire remotely sensed data from the American Landsat and the French Satellite Pour l'Observation de la Terre (SPOT). In both cases, the necessary ancillary maps and supporting data were available.

The cooperative technical exchange began when the USGS sent two remote sensing experts to China for 3 weeks in late October 1985. The Americans presented a series of lectures on the applications of remotely sensed data to surveying and mapping. Topics were remote sensing concepts, characteristics of remote sensing satellite systems, visual interpretation techniques, digital data processing and analysis techniques, statistical sampling and accuracy assessment, the role of remote sensing in GIS, and applications case studies. The lectures emphasized digital data processing techniques for preprocessing, enhancement, classification, and product generation. Detailed discussions of specific software algorithms and their speed, efficiency, and reliability also were presented during the lectures. Chinese experts at the Research Institute of Surveying and Mapping in Beijing gave briefings and demonstrations to the American scientists on NBSM computer systems, image processing software, and other topics related to the project. Following these lectures, the USGS and NBSM scientific staff continued technical consultations on the requirements for a comprehensive image processing system needed by the NBSM.

In February 1986, the NBSM sent two experts to the US for 3 weeks to study the applications of remotely sensed data to surveying and mapping in the USGS. Two weeks were spent at the USGS's Earth Resources Observation Systems (EROS) Data Center (EDC) in Sioux Falls, South Dakota, and 1 week at the USGS headquarters in Reston, Virginia. The NBSM scientists became familiar with USGS equipment, facilities, and operations during this visit. They also developed a detailed work plan to be undertaken later in the year.

In the summer of 1986, the NBSM sent two experts to the US for 3 months to perform studies and to be trained in image processing applied to specific surveying and mapping problems. During this visit, a comprehensive data set for the Black Hills study site was used for training, demonstrations, and selected studies. The work emphasized applications of digital image processing to surveying and mapping, particularly for making image maps, map revisions, and thematic maps. Also included was training on image processing procedures from the calibration of raw data to the production of final images. The digital image processing procedures applied to the data set included radiometric calibration, destriping, atmospheric correction, control point selection, geometric registration, resampling, mosaicking, contrast stretching, spatial filtering, band ratioing, training site selection, classification, postclassification refinement, shaded relief enhancements, and the design of products. Work by this team used primarily Landsat thematic mapper (TM) and digital terrain data. The NBSM experts gained an understanding of the data processing requirements and experience in analytic methods for producing image and thematic maps.

The Chinese scientists and their American counterparts spent a week at the Black Hills study site. The visit to the Black Hills area involved the field checking of several multiband combinations of TM data that were determined to be the most desirable for discriminating geologic, forest, and agricultural features. In addition, the results of the land cover classification of TM bands 5, 4, and 3 were evaluated. The team visited five intensive field sites that encompassed diverse land cover and topography. Field observations confirmed that the digital image processing procedures were applied successfully to the data set.

Most of the time during this mid-summer work session was spent at the EDC. However, team members also visited other leading remote sensing institutes and facilities in the US: the USGS headquarters in Reston, Virginia; the USGS Western Mapping Center in Menlo Park, California; the USGS Field Center in Flagstaff, Arizona; the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory in Pasadena, California; the NASA Ames Research Center in Moffett Field, California; the NASA Goddard Space Flight Center in Greenbelt, Maryland; the Environmental Research Institute of Michigan in Ann Arbor, Michigan; and the Earth Observation Satellite (EOSAT) Company in Lanham, Maryland.

Two American scientists, in turn, visited the NBSM's Research Institute of Surveying and Mapping in Beijing from mid-November to mid-December 1986 to conduct joint research using NBSM equipment and facilities and to carry out technical consultations. The two American scientists and the two NBSM experts who had recently made the trip to the USA collaborated to present to the NBSM staff a detailed description of the analytic procedures that were applied to the Black Hills data set. They displayed intermediate and final results of the joint work. The American scientists also provided technical assistance on software and hardware systems design, advice on alternative approaches to problem solving using different kinds of software, and guidance on technique development and procedures for generating products. During their visit to China, the Americans visited the Cartographic Publishing House and the Remote Sensing Laboratory at Beijing University and the Guangdong Land and Development Department in Guangzhou.

The cooperative work between the USGS and the NBSM continued in 1987 and 1988. Satellite image data had been acquired over both the Ningxiang and Black Hills study sites from the French satellite SPOT. Preprocessing of these data was carried out independently by Chinese and American scientists for their respective study sites. In the fall of 1987 and spring of 1988, two American scientists spent 4 weeks in Beijing and two Chinese scientists spent 6 weeks at the EDC. The intent of these visits was to produce a 1:100,000-scale image map of the Rapid City quadrangle in the Black Hills study site using Landsat TM data acquired in 1985 and a 1:50,000-scale image map of a part of the Ningxiang study site using SPOT data acquired in 1986. In addition, the scientists performed thematic classifications of predominant land cover types and cultural features occurring in both study sites.

Photographic products generated during these reciprocal visits included image data merged with shaded relief data in those cases where digital elevation data were available. Investigations were initiated to determine the effects of relief displacement on image maps. Map revision procedures were investigated using both digital image processing and manual image interpretation. In addition, the team tested image processing and analytic software capabilities using both USGS and NBSM computers.

During the fall of 1988 two American scientists visited the NBSM to review software development and the initial land cover classification in the Ningxiang test site. Ground truth data collected on the test site were reviewed. During the spring of 1989, two Chinese scientists visited the EDC to classify land cover of the Ningxiang test site using Landsat TM and SPOT data. Digital elevation model (DEM) data and ground truth data were used to refine the land cover classification. The team also assessed classification accuracy during this visit. The remainder of 1989 was spent compiling results of the previous 4 years of cooperative research. Procedures and accomplishments were documented and compiled for this report.

IMAGE MAPPING

Objectives

The main objective of the image mapping phase of the Protocol was to develop a comprehensive image map production facility at the NBSM. This effort began with NBSM staff coming to the EDC to study the USGS image mapping system. The Rapid City image map was generated as part of this review. After this review was completed, EDC staff traveled to Beijing to support the NBSM in transferring the important elements of the EDC system to the Beijing facility. NBSM staff then modified the system to meet their requirements. EDC staff later assisted the NBSM with system performance assessment by reworking elements of the Rapid City image map on the NBSM system and comparing the results with the map generated at the EDC. When the system was validated, work began on the Ningxiang image map, which was generated using both the NBSM and EDC systems. In this manner, the two systems demonstrated the consistency of the products that they generated, laying the foundation for applications research to be conducted jointly at both facilities.

Software Developed

The NBSM system was derived from the GEOREG software package developed at the EDC. Called the Digital Image Mapping Package (DIMP), the system operated on a Prime computer with a Pericolor display system. DIMP is functionally equivalent to GEOREG with a few modifications. Five "rough" control points, rather than four, are used to derive the first-order transformation coefficients, which initialize the transformation refinement process. The software can model distortion geometry with polynomials of up to the fifth order, although second order is used for multispectral scanner (MSS), TM, and SPOT data. The projection software models geographic, Universal Transverse Mercator (UTM), and Gauss-Kruger projections. Resampling includes nearest neighbor, bilinear, and cubic convolution. Below is a brief description of the DIMP modules:

XIN	Creates a file for parameter storage and file management.
REGMAP1	Computes rough transformation coefficients for image-to-map base registration.
REGMAP2	Selects and edits control points.
LBXYGK	Converts geographic coordinates into Gauss-Kruger projection.
LBXYUT	Converts geographic coordinates into UTM projection.
TRCOEF	Computes high-order registration coefficients for image-to-map base registration.
GEOMP	Resamples for image-to-map base registration.
VERIFY	Verifies geometrically corrected products.
STIEPT	Computes rough transformation coefficients for image-to-image registration.
REGIS	Automatically correlates for image control selection.

GEOIMI	Computes the high-order registration coeffi cients for image-to-image registration.
GEOMPI	Resamples for image-to-image registration.
TRCOPT	Calculates geodetic coordinates for tie points.
CTPME	Merges tie points and control points for mosaicking.
CCNB	Histograms overlap area for adjacent scenes in a mosaic.
INLUT	Adjusts radiometry for reducing mosaic seam artifacts.
CUTF	Cuts images along seams for mosaicking.
ZERFIL	Creates the mosaic file.
MOSAIC	Performs the mosaicking.
HPF	Performs high-pass filtering for image enhancement.

Data Sets

Black Hills Test Site

The Black Hills test site encompasses Rapid City and a large area including most of the Black Hills National Forest and surrounding rangeland and agricultural land. The landscape is mountainous, with an overall topographic relief of approximately 800 to 1,000 meters. The area is sparsely populated and has only a few towns and ranches and a transportation network that is well developed but not complex. High-altitude aerial photographs were available of the Black Hills area and were acquired during flights in September 1981 and September 1982, under the auspices of the National High-Altitude Photography Program. Other map and digital data sources also were available for this area. The Black Hills region is a unique geological and ecological area that has been studied extensively (fig. 1). The surrounding agricultural land is mostly dryland wheat with small fields of irrigated cropland adjacent to the Belle Fourche River and Rapid Creek. The grassland is used for livestock production.

As a result of studies of the Black Hills area by remote sensing and GIS scientists, several data sets are available. One of the most important is a high-resolution DEM data set. The data set is a mosaic of a large number of USGS 1:24,000-scale DEMs. The data set is complete for the Black Hills, but incomplete for some of the agricultural and rangeland area surrounding the Black Hills. Lower resolution digital elevation data from two USGS 1:250,000-scale quadrangles were available for the entire study area and were used to supplement the data in areas where the high-resolution DEM data did not exist.

The primary data used for the image mapping activity in the Black Hills study area were two Landsat TM images acquired on August 9, 1984. The images (identification nos. Y5016117054X0 and Y5016117060X0) were consecutive scenes in the same orbit path (path/row 33/29 and 33/30). The consecutive sequence of the scenes was advantageous

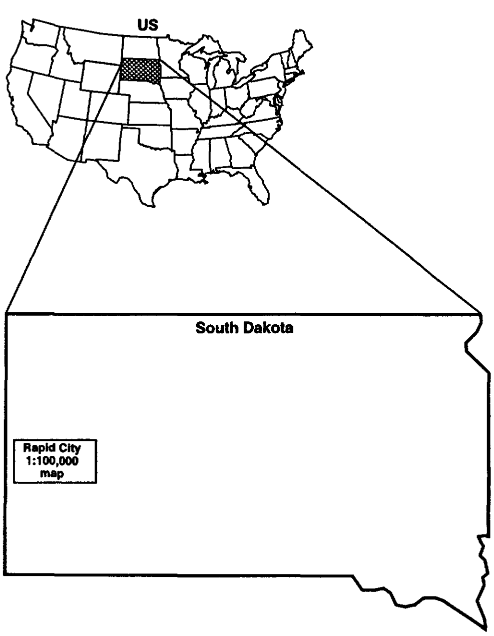

Figure 1. Map showing the location of the Rapid City image map in the Black Hills of South Dakota.

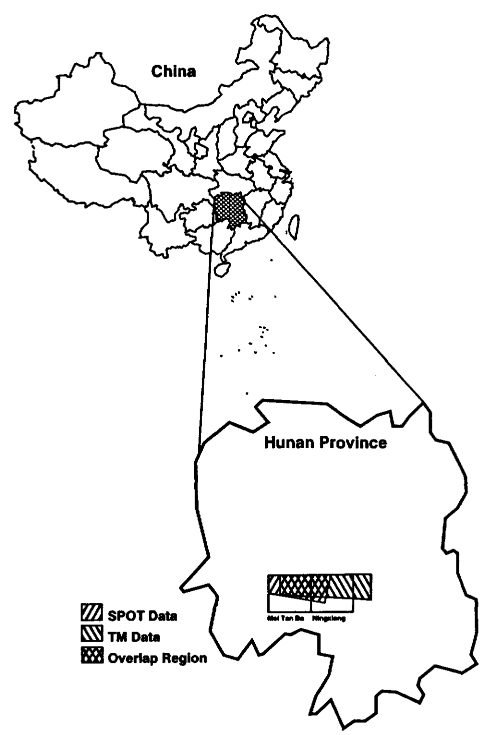

Figure 2. Map showing the location of the Ningxiang study area in Hunan Province.

because the radiometry of the scenes was identical and no special enhancements or processing were necessary when the scenes were mosaicked for the study area.

The final image map of Rapid City published by the USGS conformed to USGS standards and included map collar information. Prior to publishing, an intermediate photographic image map product was made for review by the cooperators. The intermediate map included collar information such as scale bar, location diagram, 10,000-meter grid lines, descriptive text, and latitude and longitude location. Portions of the text were in both English and Chinese.

Ningxiang Test Site

The Ningxiang study area (fig. 2) involved the Ningxiang and the Mei Tan Ba 1:50,000-scale quadrangles. The Ningxiang area is primarily an agricultural region composed of both irrigated and nonirrigated cropland. It has rolling topography with elevation differences of 200 to 300 meters. There is some forest land at high elevations. The area is densely populated and has many towns and villages and a complex transportation network. The NBSM recently obtained high-altitude aerial photographs of the study site. The aerial photographs were acquired by a jet aircraft at approximately 5,100 meters above the terrain. The photographs obtained during this flight, as well as existing topographic and thematic maps, were available. TM data acquired August 25, 1987, covered approximately the upper three-fourths of the Ningxiang quadrangle and the same portion of the east half of the Mei Tan Ba quadrangle. These data were geometrically corrected and registered to a map base. Restoration was used as the resampling procedure to derive 20-meter resolution data. Figure 3 shows the Ningxiang test site as extracted from bands 5, 4, and 3 of the TM data. The SPOT data acquired on September 21, 1986, for the Ningxiang test site covered approximately the upper three-fourths of the Mei Tan Ba quadrangle and the same portion of the west half of the Ningxiang quadrangle. These data were geometrically corrected and registered to a map base. Restoration was used as the resampling procedure to derive 20-meter resolution data.

Topographic data for the Mei Tan Ba quadrangle were generated by digitizing linework from 1:10,000-scale maps of the quadrangle. This linework was digitized in ARC/INFO by NBSM personnel, brought to the EDC, and converted to raster format for merging with the spectral data. The topographic data were used to create a color-coded, shaded relief map of the Mei Tan Ba quadrangle.

A customized map collar was prepared for each of the quadrangles. Line-work was developed on the Intergraph system and consisted of a collar and graticules of a 2,000-meter grid in a projection of Chinese origin. English and Chinese text were prepared for labeling each quadrangle.

The TM and SPOT data were merged to produce the image map for each quadrangle. Histogram matching was used to spectrally combine the two data sources. These combined images were further enhanced by filtering and contrast stretching the data.

Analysis

Black Hills Test Site

Geometric Registration

To demonstrate EDC geometric registration and digital mosaicking capabilities, a digital mosaic over the Rapid City, South Dakota, 1:100,000-scale quadrangle was prepared from the two Landsat TM images. Approximately 25 ground control points were selected from 1:24,000-scale topographic maps for each of the two images. The ground control points were reprojected to the UTM projection and used in the Large Area Mosaicking System (LAMS). LAMS is a subset of the Land Analysis System (LAS) image processing system and makes mosaics of digital data sets. Digital mosaicking involves adjusting the geometric and radiometric discontinuities between images along mosaic seams. The two images were resampled to 25-meter resolution using cubic convolution resampling. Because the two images were consecutive scenes along the same orbital path, no radiometric adjustments were required. Geometric verification showed a total root-mean-square error (RMSE) of 2.48 pixels with a line and sample RMSE of 1.49 and 1.98 pixels, respectively. The foregoing table reports the geometric verification results for the two images.

	Output		Residual		Relief Displacement	
Point	Line	Sample	Line	Sample	Line	Sample
1	433	290	1.0	4.0	0.48	2.76
2	318	337	-1.0	4.0	0.36	2.06
3	276	1549	1.0	1.0	0.00	0.00
4	307	1423	0.0	1.0	0.05	0.30
5	1101	2399	0.0	0.0	-0.02	0.10
6	1363	1511	-2.0	1.0	0.24	1.39
7	1820	1569	-2.0	1.0	0.22	1.26
8	2241	1509	2.0	0.0	0.28	1.63
9	1412	816	0.0	3.0	0.53	3.04
10	1253	2161	0.0	1.0	0.00	0.04
11	1296	2403	2.0	2.0	-0.02	-0.07
12	420	2595	1.0	1.0	0.00	0.00
13	2064	2870	3.0	0.0	-0.01	0.00

Image Enhancement

To enhance the local information in homogeneous

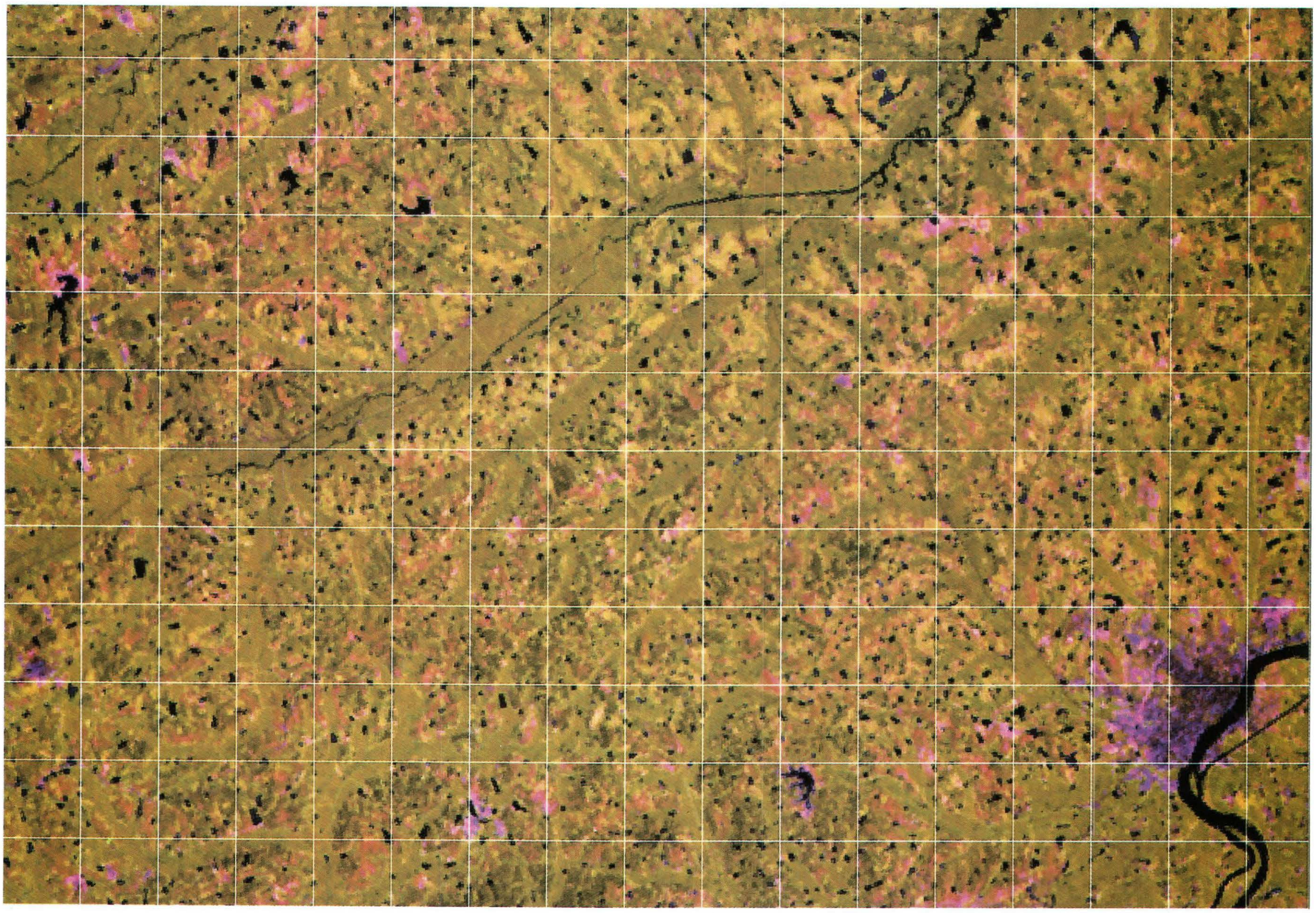

Figure3. Image showing the Ningxiang test site as extracted from bands 5, 4, and 3 of the TM data.

areas and to increase the effectiveness of subsequent contrast enhancements, a large-kernel (151- by 151-pixels), high-pass spatial filter was applied to the digital mosaic. A small-kernel (5- by 5-pixels), high-pass filter was then applied to enhance the high-frequency information in the image. To improve the apparent contrast in the final mosaic, a piecewise linear contrast enhancement was applied to the filtered images. The following break points were selected from the cumulative histograms for each of the three bands:

Band 4 (red)	From:	20	62	87	113	205	254	255
	To:	0	45	147	215	245	245	255
Band 3 (green)	From:	18	41	62	83	175	254	255
	To:	0	30	135	200	245	245	255
Band 2 (blue)	From:	33	46	58	70	122	254	255
	To:	0	25	125	190	245	245	255

The NBSM transferred film transparencies of the final digital mosaic with digital map collar information to the USGS for reproduction in lithographic form. A copy of the corresponding topographic map was printed on the reverse side of the final product.

Special Product Generation

Areas of joint interest were the development of shaded relief images derived from DEM data and images in which other digital data are draped over the shaded relief image(s). Several experimental shaded relief images were produced from the high-resolution DEM and TM data using the LAS software.

The LAS software uses a variety of illumination angle and azimuth directions to produce shaded relief images. The objective of the work was to demonstrate how different illumination conditions would affect the products. A series of nine 512- by 512-pixel images were produced using only the DEM data. The images illustrate how variation in illumination conditions can be used to enhance geologic faults and lineaments, which are very extensive in the Black Hills. The images also demonstrate how the selection of the correct illumination angle can emphasize slope and aspect (see fig.4).

A series of 512- by 512-pixel images of satellite data draped over the shaded relief image was also produced. The composite of TM bands 4, 3, and 2 depicted the scene as a false-color image. Two methods of draping data over the shaded relief image were tested. The first approach was to merge each of the three bands of the false-color composite

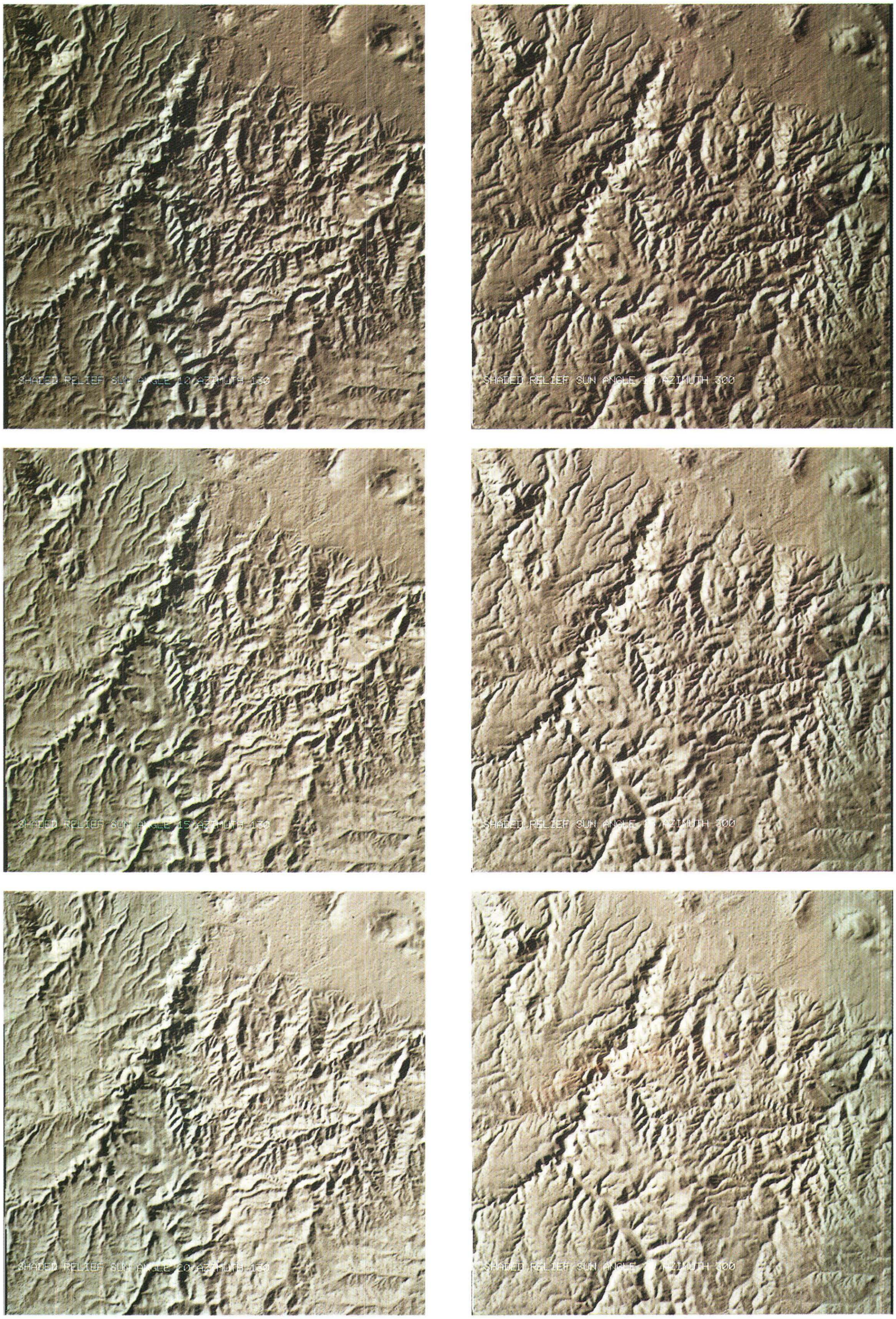

Figure 4. Shaded relief image results of the Black Hills area created from digital elevation data.

separately with a copy of the shaded relief image and then recombine the red-green-blue (RGB) enhanced bands for the final product. The second approach was to transform the three RGB bands of the satellite image to hue-intensity-saturation (HIS) data, substitute the shaded relief information for the intensity band of the HIS data, and retransform the three bands back to RGB. The results are similar in appearance, but the HIS approach has more versatility for enhancing image features in the final color representations. The results also demonstrated how shaded relief images can make satellite data easier to interpret. All of the images were produced as film transparencies for duplication.

Ningxiang Test Site

Geometric Registration

A TM/SPOT digital mosaic was prepared for the Ningxiang test site. Geometric control was selected by the NBSM staff using control point selection software developed on NBSM computer systems. The control points were transferred to EDC's LAMS for digital mosaicking. Both images were transformed using cubic convolution resampling to the Gauss-Kruger projection at 20-meter resolution.

To ensure the accuracy of the control point selection, selected areas were digitally magnified. A small, moveable window on the display screen was positioned over the selected control point. The window was then magnified 10 times, resulting in a control point selection error of less than one pixel. Control points were selected where ground features showed well-defined intersections of roads, field boundaries, rivers and roads, and so on. A total of 15 control points were selected on the SPOT image. Geometric verification showed an RMSE of 0.71 pixels, with a line and sample RMSE of 0.57 and 0.43 pixels respectively.

SPOT Residual Data

	Output		Residual	
Point	Line	Sample	Line	Sample
1	1464	775	0.26	-0.02
2	1292	1007	-0.61	-0.14
3	1128	791	0.05	-0.15
4	1230	549	0.69	0.06
5	1283	172	0.40	-0.33
6	1271	311	-1.06	0.40
7	903	795	0.24	-0.10
8	1007	960	0.25	0.17
9	687	1109	-0.26	-1.06
10	1031	1419	0.57	-0.33
11	908	1318	-0.52	0.89
12	453	902	0.96	0.44
13	368	846	-0.77	0.04
14	155	71	-0.03	-0.02
15	67	683	0.02	-0.07

A total of 17 control points were selected for the TM image. An RMSE of 0.83 pixels was shown by geometric verification, with a line and sample RMSE of 0.58 and 0.83 pixels respectively.

TM Residual Data

	Output		Residual	
Point	Line	Sample	Line	Sample
1	893	533	0.06	-0.29
2	768	685	0.25	-0.55
3	549	790	1.04	0.74
4	545	1159	0.03	0.91
5	870	866	-0.23	-0.30
6	781	107	-0.03	0.43
7	803	86	0.45	0.78
8	634	337	-0.75	-1.44
9	515	1999	0.67	-0.40
10	550	2016	0.60	-0.46
11	827	2003	-0.63	0.50
12	586	1589	0.23	0.24
13	614	1484	-0.34	-0.30
14	299	1737	-1.01	0.13
15	194	74	-0.56	0.16
16	464	206	-0.49	-0.09
17	43	75	0.66	-0.16

Image Enhancement

To avoid enhancing the resolution differences between the TM and SPOT portions of the digital mosaic, no spatial filters were applied to the final product. The following piecewise linear stretch was applied to improve the overall spectral contrast of the image.

Red	From:	0	7	38	89	144	171
	To:	0	5	30	145	215	255
Green	From:	0	10	15	28	64	103
	To:	0	0	25	130	190	255
Blue	From:	0	21	25	35	52	73
	To:	0	0	20	120	180	255

Special Product Generation

Image maps of the two 1:50,000-scale quadrangles (Mei Tan Ba and Ningxiang) were produced, and a map collar with Gauss-Kruger coordinates and Chinese map titles and labels were photographically reproduced. This product represented the first multisensor mosaic produced by the USGS.

Topographic data for the Mei Tan Ba quadrangle were generated from digitized hypsography from 1:10,000-scale maps provided by the NBSM. The data were converted to raster format in 20-meter cells. A shaded relief image was produced from the DEM data using LAS software with a simulated sun location 10° above the eastern horizon. The original elevation values were then grouped into representative ranges and draped over the shaded relief image to produce an enhanced color image. Custom map collar information was merged with the image, and the image was rendered as a color ink-jet plot.

THEMATIC MAPPING

Objectives

Both the US and PRC need land cover and land use information. The size of the countries and the diversity of traditional land cover and land use information is a motivation for using high-resolution satellite images to produce new information or update existing information.

Research has shown that accurate and detailed information can be extracted from the spectral information in Landsat TM data and SPOT data. The success of such an effort can often depend on the chosen data classification approach. Important factors, including the availability of existing ground information, the economics of gathering new ground information, the complexity of the land being mapped, the classification framework, and the availability of supporting data such as topography, often dictate classification decisions. The objective of this investigation was to evaluate classification approaches. Several elements of classification were addressed, including selection of training data, data clustering, and postclassification refinement.

Another objective was to help establish priorities for software development and implementation on the NBSM computer system. Developing a system for classification can be difficult. The identification of the key approaches to classification and software performance issues were, therefore, important.

Software Developed

The Maximum Likelihood Decision Rule (MLDR) has a high classification accuracy and was used in some cases for this investigation. However, MLDR is a supervised classification and requires that all desired classes be present in the image. To get a better representation of classes in the image, unsupervised classification software, known as the Iterative Self-organizing Clustering Program, was added to the system. In addition, the NBSM developed editing functions to correct errors found in the classified image. These functions used a cursor to point to the incorrect classification for relabeling. To use DEMs to refine the classification results, the NBSM developed additional functions to calculate slope and aspect images. These functions were then used to modify the classifications where appropriate.

Data Sets

Black Hills Test Site

TM data for the Black Hills test site were acquired on August 9, 1984. The two images were registered to a map base in the UTM projection. The data were resampled to 20-meter pixels using the cubic convolution procedure.

Ningxiang Test Site

The Ningxiang test site involved the Ningxiang and Mei Tan Ba 1:50,000-scale quadrangles. TM data, acquired August 25, 1987, covered approximately the upper three-fourths of the Ningxiang quadrangle and the same portion of the east half of the Mei Tan Ba quadrangle. These data were geometrically corrected a second time for the thematic mapping work done during early 1989. The data were registered to a map base and resampled to 20-meter resolution using the nearest neighbor interpolation method.

The SPOT data for the Ningxiang test site were acquired September 21, 1986, and covered approximately the upper three-fourths of the Mei Tan Ba quadrangle and the same portion of the west half of the Ningxiang quadrangle. These data were geometrically corrected and registered to a map base. For the early 1989 classification work, the data were resampled to 20-meter resolution using nearest neighbor interpolation to match the resampling procedure of the TM data.

Topographic data for the classification work were a combination of the manually digitized 1:10,000-scale data for the Mei Tan Ba quadrangle and the 1:50,000-scale data for the Ningxiang quadrangle. The linework was digitized by the NBSM in ARC/INFO and was brought to the EDC. The registered data were merged, and a specially designed spatial filter was used to smooth the transition area between the two scales. These data were used to calculate aspect and slope images for further analysis.

The NBSM made a land cover map for the test site by interpreting 1:10,000-scale color-infrared aerial photographs. The map was digitized in ARC/INFO, brought to the EDC, and converted to raster format for subsequent analysis. There were 19 Level III land use classes. A number of attribute errors were discovered in the data that required correction before the data could be used in the accuracy assessment.

Because the test area that compared TM and SPOT spectral classification accuracies was a combination of portions of the two original quadrangles, new linework was constructed for the final products. This linework included a map collar, a graticule of a 2,000-meter grid in a projection of Chinese origin, and a location map showing what portions of the two quadrangles were involved in the test area. A similar set of linework was also constructed for the results of the TM scene analysis.

Analysis

Black Hills Test Site

Data Preparation

The primary data sources for the thematic mapping of the Black Hills test site were the two Landsat TM scenes acquired consecutively on August 9, 1984. These data had been geometrically registered by NBSM scientists during the 1986 visit to the EDC. The data were resampled to 30-meter cells (to match the spatial resolution of the existing DEM data set) and mosaicked. Note that the 30-meter Landsat data were not used in the image mapping process. TM bands 2, 3, and 4 were chosen for the classification process.

The high-resolution (30-meter) DEM data were available and used for postclassification refinement. Slope, aspect, and elevation images were derived from the DEM data.

Existing high-altitude aerial photographs of a portion of the study area, which had been acquired in 1983, were obtained for use as ground truth data and to aid in selecting training sites.

An image of the 1:2,000,000-scale digital line graph transportation network also was used as an overlay to locate ground sites during the field verification process.

Class Statistics Development

The thematic mapping effort for the Black Hills test site was conducted in 1986. At this time, the only realistic approach to gathering training statistics using LAS software was the use of an unsupervised method. Methods for extracting individual, irregularly shaped training sites were still under development.

The method that was used for selecting the training sites was a modified cluster block approach. The process involved selecting eight blocks, each 200 lines by 200 samples. The eight blocks corresponded to areas with existing aerial photographs. The blocks represented the existing land cover classes within the Black Hills and surrounding region. The eight blocks were mosaicked into one image, 400 lines by 800 samples, and input to the ISOCLASS clustering algorithm.

The ISOCLASS algorithm adjusts the parameters that control the number of clusters, the standard deviation limits, and the distance between cluster means. The first clustering attempt used the default parameters. The default number of classes was 16. The first clustering test was compared with the aerial photographs and showed that more spectral classes were desirable. A second attempt was made requesting 36 spectral classes.

Analysis of the statistical information provided by the ISOCLASS algorithm showed good separation of classes. The information classes were labeled using the aerial photographs as ground information. The labeling process provided an opportunity to discuss and formulate a classification framework that was suitable for the data. Eight information classes were identified: barren/disturbed, water, grassland, irrigated cropland/shrubs, nonirrigated cropland, conifer forest, mixed conifer/deciduous forest, and deciduous forest.

Several other clustering attempts used variations of primary parameters to demonstrate the effects of these manipulations. Still other clustering attempts used an unsupervised approach. Random samples of pixels were chosen and input to the ISOCLASS algorithm. The parameters and sample sizes were varied to better understand these variables.

The results of the modified cluster block approach were chosen for use in the classification process. The statistical file generated by the ISOCLASS algorithm became a part of a maximum likelihood and a minimum distance classifier. The entire Black Hills test site was classified. Comparison of the results indicated a high degree of similarity. A comparison of processing times showed very little difference. The conclusion was to use the easier method at the NBSM.

Postclassification Processing

Postclassification processing uses auxiliary information to refine the information classes. The auxiliary information is usually in the form of images derived from other data sources. Typical auxiliary data include soils classes, slope, aspect, and elevation. Logical formulations and linear models incorporating the auxiliary data are used to describe an information class. For instance, logic dictates that cropland should not exist on a slope greater than 30 percent. If a comparison of the information classes from a spectral classification with slope information identifies the existence of cropland on a steep slope, then the data in the spectral classification should be redefined as barren land.

The Black Hills test site is an area where topographic data are very useful in a postclassification process. The geologic structure of the Black Hills is a dome that rises significantly from the surrounding land. The forest dominates the steep slopes in the higher elevations. The land surrounding the dome is reasonably flat and used for cropland and grazing.

The spectral classification of the Black Hills test site resulted in the definition of an irrigated cropland/shrub class. This mixed class was a result of the inability to separate shrubs in the valleys within the forest from areas of irrigated agriculture in the area surrounding the forest. Using the topographic data in a postclassification process allowed the separation of this spectral class into two information classes. A model formulation redefined irrigated cropland occurring at elevations higher than 1,500 meters as shrubs. Formulations that are made using sound logic and appropriate auxiliary data can be useful in increasing the accuracy of spectral classifications.

Another postprocessing technique that was used to improve the accuracy of the classification was smoothing or area filtering. Often spectral classification produces "noisy" results. The noise is most evident when it appears in what should be a homogeneous region such as a large agricultural field. The noise can be removed by using smoothing filters on the data. One common approach is to move a 3- by 3-pixel, or larger, filter over an image. A tally is made of the classes occurring in the window. Rules are usually predefined that direct the level of smoothing to occur. The simplest rule is to change the center pixel to the class value that dominates the window, with priorities defined for situations with no clearly dominant class. Other variations of the rules can include changing only the center pixel if a specific surrounding class exceeds a threshold value, or never changing the center pixel if it is the water class.

The results of this type of smoothing can vary dramatically. If care is not taken, the smoothing also can reduce the accuracy of a classification. Several methods were tested using a subset of the Black Hills test site. Each method was evaluated for the effects it appeared to have on the data. Figure 5 illustrates the results of some of the smoothing processes.

Another technique that can be used to remove noise is area filtering. Area filtering is a process in which homogeneous polygons or groups of contiguous pixels of the same class that do not meet a size threshold are removed by merging them with surrounding classes. For instance, a group of fewer than 10 pixels can be merged into adjacent classes. There are rules that can be used to guide the area filtering. A common application would be to establish a special threshold for each class. For example, small water bodies could be protected by setting a high threshold value. Control over class merging can be applied by defining which classes can be merged with others.

Several procedures using this technique were evaluated. This method is most useful if the size of an area is an important criteria in a land management situation.

Accuracy Estimation

The accuracy of the classification was not verified. During the testing of classification methods, most of the accuracy verification was done with the aerial photographs. The areas used in the cluster block analysis and other areas where photographs existed were used in this process. A 5-day field trip was made to the Black Hills test site to visit several ground sites. The sites were representative of the different land use and land cover types in the test site. Color plots of the classification results were produced at 1:250,000-scale. The accuracy was judged qualitatively by comparing the classification results with a visual inspection at the selected ground sites. In general, the classification was more accurate in the forested regions in the Black Hills than in the surrounding agricultural areas. Some of the inaccuracy was because the dates of the images used in the study (August) did not optimally depict agriculture in this region.

Ningxiang Test Site

Data Preparation

NBSM staff brought to the EDC in March 1989 geometrically corrected and registered TM data (bands 1, 2, 3, 4, 5, and 7) at 20-meter resolution using nearest neighbor resampling and digital raster ground truth data at 10- and 20-meter resolution. The ground truth data had been photointerpreted from 1:10,000-scale color-infrared aerial photographs (September 1986), digitized by the NBSM's GIS group using their Land Information System, and reformatted to ARC/INFO format. These ground truth data contained 19 Level III land use classes (table 1). The NBSM scientists also brought digital terrain data for the Ningxiang quadrangle that had been digitized manually from a 1:50,000-scale map. These data also were geometrically corrected and registered at 20 meters to the Chinese metric projection similar to the UTM. Resampling of the SPOT data ensured that any differences in classification performance between the TM and SPOT classifications were not due to different preprocessing techniques. The SPOT data that had been registered at the EDC in 1988, using cubic convolution resampling, were reprocessed in March 1989 using the nearest neighbor method of resampling.

Table 1. Ground truth land cover classes and their digital values.

Original data Pixel value & name		
11 Irrigated	41 Natural Grasslands	99 Miscellaneous
12 Dryland Agriculture	51 Cities & Towns	33 Sparse Forest
13 Irrigated Agriculture	52 Rural Residential	81 Mud Flats
21 Fruit Trees	53 Industrial	32 Brush/Shrubs
22 Mulberry Trees	62 Highways	72 Ponds and Reservoirs
23 Tea	71 Rivers	31 Forest
24 Rubber Trees		

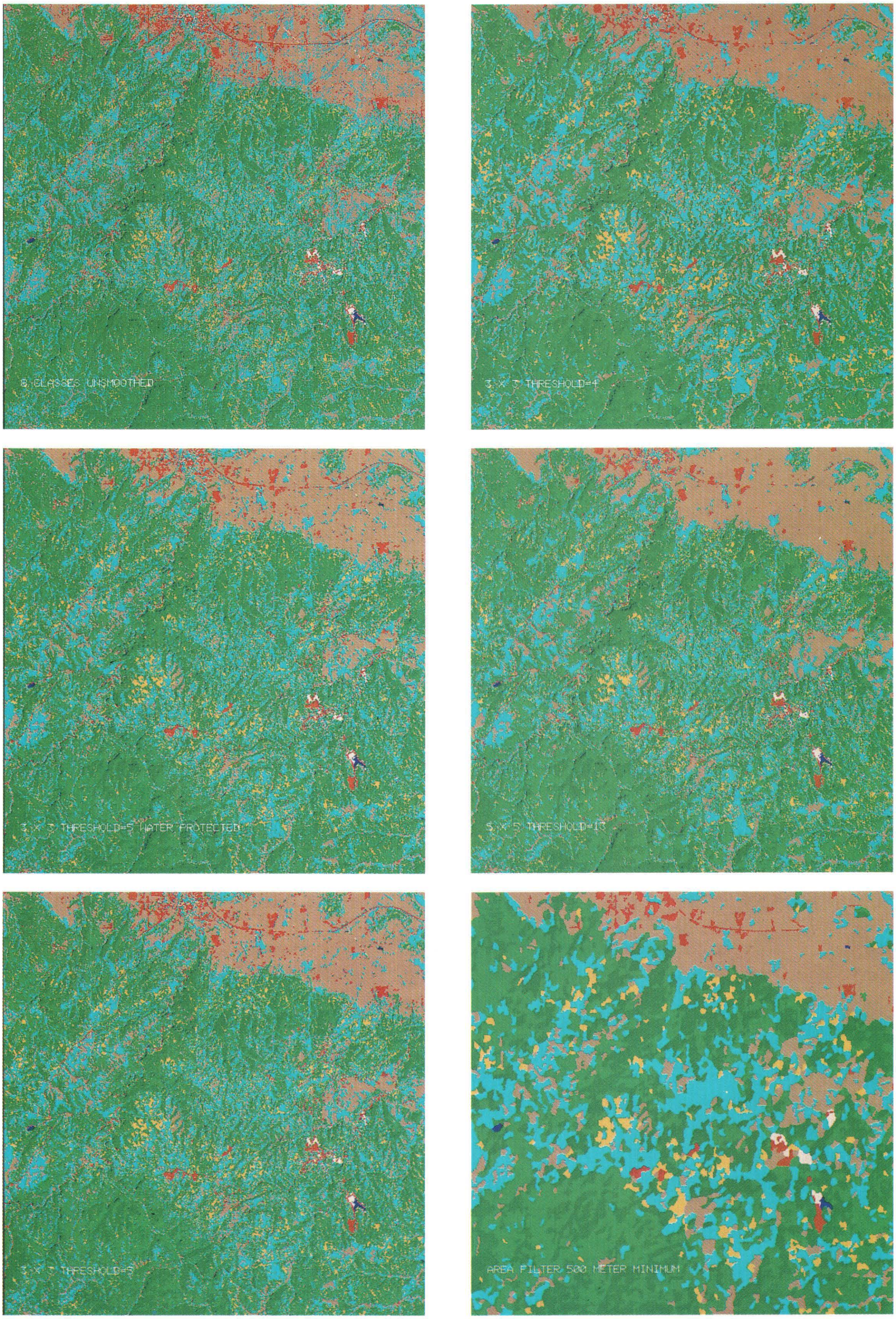

Figure 5. Comparison of the raw image of the Black Hills classification results and the results of smoothing or area filtering techniques.

Figure 6. The NBSM and EDC team comparing the ground truth data with aerial photographs.

Anticipated final products from the 1989 4-week working session at the EDC were:

1. TM, 6-band classification
2. TM, bands 3, 4, and 5 classification
3. TM, bands 2, 3, and 4 classification
4. TM, tasseled cap transformation
5. TM, principal components transformation
6. SPOT, three-band classification
7. TM, ground truth classes and spectral statistics
8. SPOT, ground truth classes and spectral statistics
9. Ground truth and topographic data contingency tables
10. Postclassification refinement of the best results using digital slope data

Research topics addressed by the above products and other planned work included:

1. TM band combinations for classification
2. TM spectral transformations for information
3. TM vs. SPOT comparison
4. Determination of optimum classification performance
5. Land cover and topography relationship
6. Textural analysis
7. Temporal analysis (discussion only, analysis not possible with present data sets)

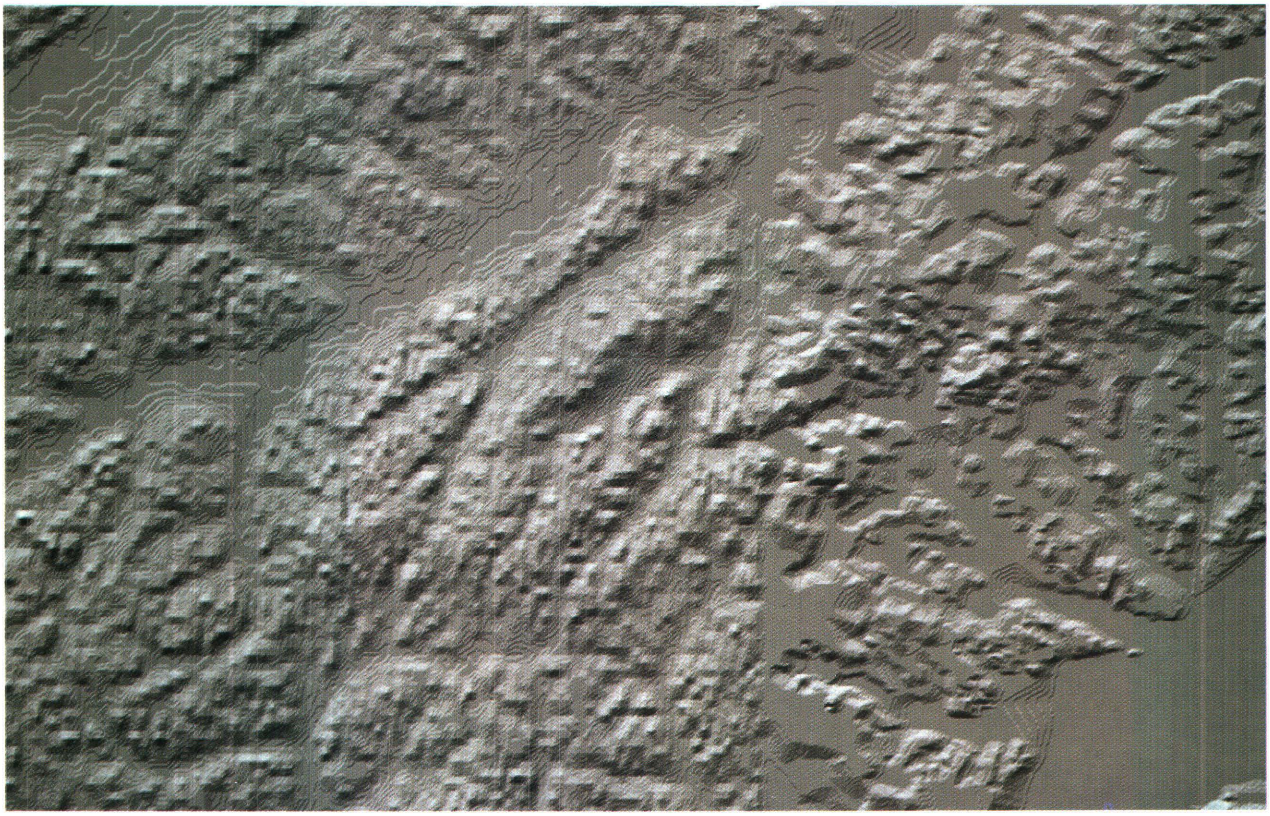

Figure 7. A shaded relief image of the Ningxiang test site created with merged 1:10,000- and 1:50,000-scale digital terrain model data.

A detailed examination of the digital ground truth data revealed a significant number of attribute errors. These errors prohibited the use of the original ground truth data for accuracy assessment. Correction of the errors by an EDC digitizing technician was not completed until three days before the NBSM science team's scheduled departure. The use of the corrected ground truth data in classification performance assessment is discussed later in this report. Figure 6 shows some of the participating scientists evaluating the ground truth data.

During this time, an NBSM scientist evaluated the digital terrain data for the Ningxiang quadrangle and mosaicked it with the Mei Tan Ba quadrangle to the west. The western data set had been digitized during the third year of the Protocol by the NBSM using 1:10,000-scale topographic maps. During the fourth year, the NBSM GIS group digitized the Ningxiang data from a 1:50,000-scale map. As was expected, the data collected from the smaller scale topographic maps were much more sparse and resulted in a more coarse representation of the terrain. The mosaic of the two maps was very close spatially, but the join line between the two different resolution data sets was

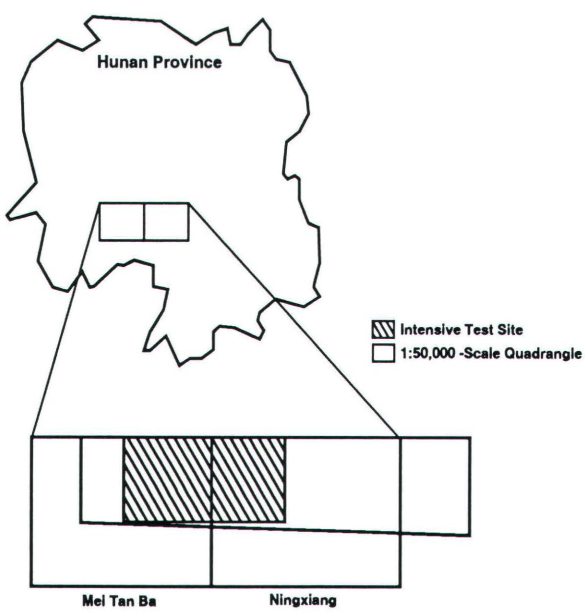

Figure 8. Map showing the location of the intensive test site located in the TM and SPOT overlap region of the Ningxiang study area.

quite apparent. An NBSM scientist met with an EDC senior image processing scientist in the Digital Image Sciences Section to determine an appropriate solution to the problem. A spatial filtering procedure that involved the application of a 1- by 5-pixel window with relative weights on either side

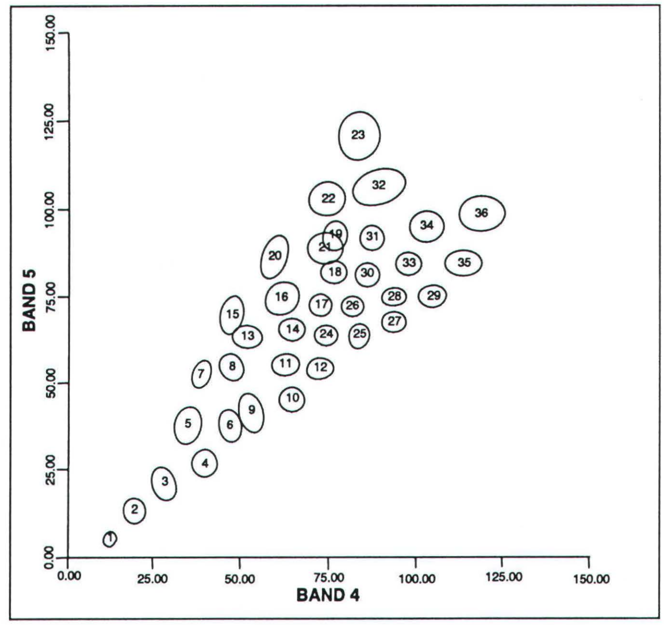

Figure 9. Ellipse plots of the 36 spectral cluster classes calculated for TM bands 3, 4, and 5. Ellipses represent one standard deviation about each class mean.

of the join line that would digitally provide a smoother transition between the two maps was developed by EDC. The visual result was very satisfactory considering the quality of the lower resolution digital terrain model (DTM) data. Using the resulting data set, an NBSM scientist extracted the test site area and generated aspect, slope, and shaded relief products from the DTM data values. Figure 7 shows the shaded relief image of the Ningxiang test site created with the merged DTM data sets.

Statistics Development

For the land cover classification task, a small 582- by 840-pixel test site was selected and was located so that both the TM and SPOT data were available over the entire site (see fig. 8). An NBSM scientist selected thirty-six 31- by 31-pixel cluster blocks representing the 18 land cover classes. These were assembled into a single composite image 186 by 186 pixels. Three sets of statistics were calculated for this 36-block image using (1) TM bands 1, 2, 3, 4, 5, and 7; (2) TM bands 2, 3, and 4; and (3) TM bands 3, 4, and 5.

Ellipse plots of the class statistics from the TM ISOCLASS results (bands 3, 4, and 5) were evaluated (see fig. 9). Variations in ISOCLASS parameters controlling TM cluster-based intraclass standard deviations were investigated as they related to spectral signatures found in agricultural regions of China. With TM data, the maximum allowable standard deviation per class needed to be set at 6.5 to have at least 80 percent of the clusters meet the

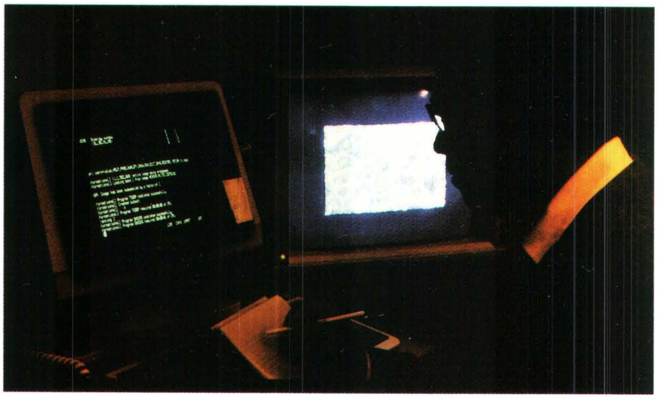

Figure 10. An NBSM scientist checking the initial classification results using the VAX 11/780 computer at the EDC.

criteria. At this point the iterative sequence of splitting clusters was halted and an iterative sequence of combining clusters was initiated. The result of this processing was a set of 29 spectral clusters after 9 iterations. These results, from an application of LAS software, were replicated on the Interactive Digital Image Manipulation System (IDIMS) using similar class means to evaluate a new LAS ISOCLASS implementation.

Spectral separability between the 29 LAS-derived TM cluster classes was calculated using transformed divergence (LAS function DIVERGE) and resulted in an average divergence value of 96.5842 (which is equal to a divergence value of 1,932 on the traditional 2,000-level saturation scale). IDIMS results gave a transformed divergence value of 1,941. Those more familiar with MSS data might note that this is a much higher average divergence than expected with the wider band MSS data. The use of

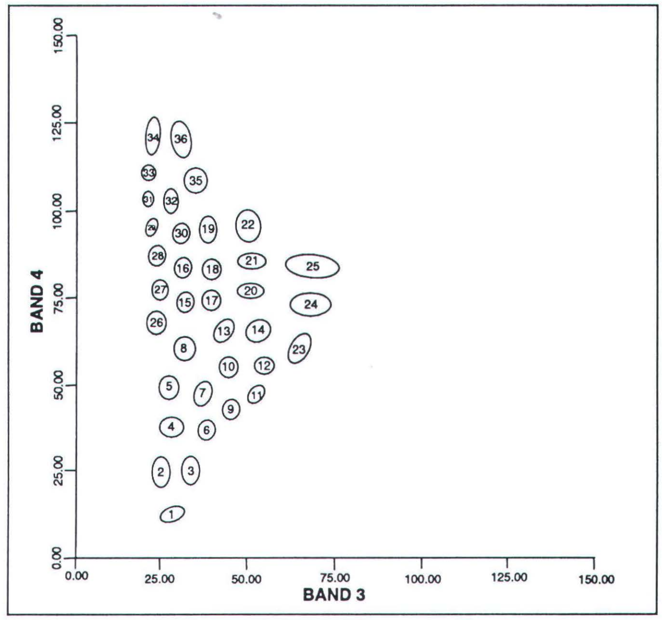

Figure 12. Ellipse plot for the best TM two-band combination (bands 3 and 4) calculated from spectral values in TM bands 2, 3, and 4.

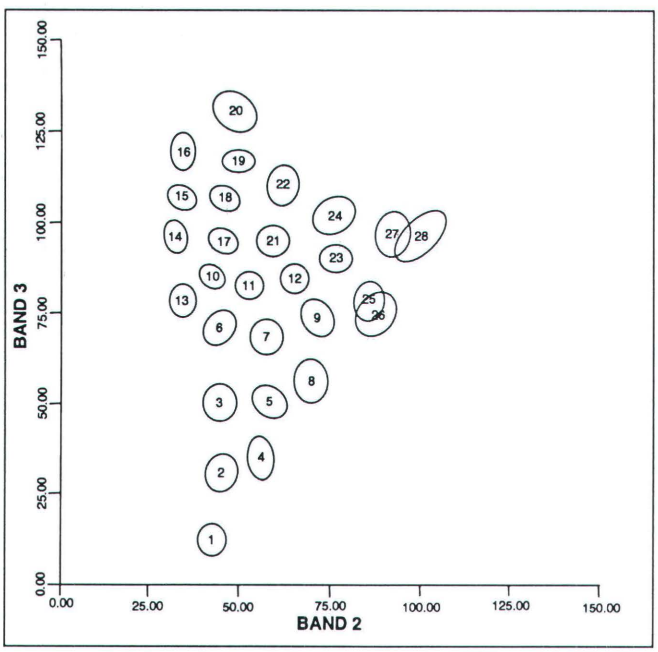

Figure 11. Ellipse plots of the 28 spectral cluster classes calculated using SPOT bands 1, 2, and 3. Ellipses represent one standard deviation about each class mean.

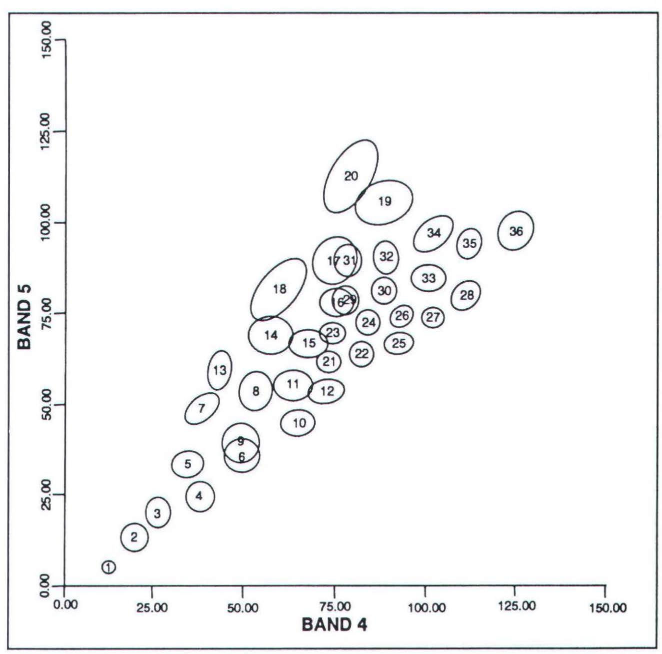

Figure 13. Ellipse plot for the best TM two-band combination (bands 4 and 5) calculated from spectral values in TM bands 1, 2, 3, 4, 5, and 7.

TM band 5 (middle-infrared) seemed to contribute to greater TM class separability.

An NBSM scientist worked with the cluster results, aerial photographs, and ground truth map to link the 29 cluster classes with the corrected ground truth information classes (fig. 10) . He found that a reasonable relationship could be made between these for 10 information classes.

The SPOT data (multispectral bands 1, 2, and 3) were then classified using statistics developed from the same ground-referenced training locations as had been used for the TM data. The training locations were thirty-six 31- by 31-pixel blocks (7.14 percent of the test site pixels) that were mosaicked into a single image and then clustered using 9 iterations with (1) maximum number of clusters specified at 36, (2) minimum cluster class size at 30 pixels, (3) maximum within-cluster standard deviation set to 6.5, and (4) minimum intraclass separability at 2.3. The resulting SPOT ISOCLASS statistics contained 28 cluster classes. An ellipse plot of the cluster results is shown in figure11.

The classification test site was then expanded to the larger TM data set (1,463- by 2,440-pixels). Because there was a significant change in land use and land cover types in the eastern portions of the Ningxiang map sheet, which was not apparent in the smaller central test site used earlier, it was necessary to select additional training sites for these cover types. Consequently, 12 additional 31- by 31-pixel samples were chosen to represent the change in agricultural practices, the more rugged terrain, and the more heavily forested areas. These 12 sites were added to the 36 previous sites, and the ISOCLASS algorithm was run on the new mosaicked 48-block, 248- by 186-pixel training data set. The resulting 36 clusters were obtained using the identical cluster parameter settings as used with the smaller TM test site.

Having become familiar with the TM data through the selection of training sites and the refinement of the spectral statistics for the band 3, 4, and 5 subset, the scientists began processing the other classification products. Specifically, class statistics were calculated for the various band combinations and refinements were made prior to generating classification results for TM band combination 2, 3, and 4 and TM band combination 1, 2, 3, 4, 5, and 7. Ellipse plots, divergence values, and ISOCLASS cluster maps were used to refine and identify the 19 cluster classes for the band 2, 3, and 4 combination and the 36 cluster classes for the band 1, 2, 3, 4, 5, and 7 combination. Ellipse plots for the best combination of two bands from each of these two statistical files are shown in figures 12 and 13.

Classification Approach

The BAYES maximum likelihood algorithm used 29 cluster class statistics to classify the smaller TM study site and the 36 class statistics to classify the larger TM site. A chi-square image also was calculated for each classification result to measure the probability of correct classification for each pixel in the study site. A color Calcomp plot of the 10 information classes resulting from the classification was produced at a scale of 1:30,000.

Postclassification Processing

Because of the complex land cover patterns in this area of China and the extremely small field sizes, the scientists decided that nominal filtering techniques (Fosnight, 1987) might enhance both the visual rendering of the classification and the performance statistics for the final classification product. Consequently, after consulting with an EDC scientist concerning the theory and implementation of nominal filtering techniques, the scientists ran two tests on the TM bands 3, 4, and 5 classification results. Nominal filtering allows the analyst to spatially filter the classification result while controlling the size of the regions, the classes affected, and the classes to which the regions are reassigned. This process requires a matrix of class-pair weights to specify which class reassignments are allowable. The matrix was developed for the test site on the basis of spectral statistics for each class. If a very small region is similar to its neighboring regions, then it is acceptable to reassign that small region. In addition, the class of the larger neighboring region that is adjacent to or surrounds the small region is the class to which the small region is reassigned, if the spectral statistics are acceptably similar on the basis of the weighing table.

The nominal filtering tests that were conducted used a weight table that was calculated from the ISOCLASS statistical file. The difference between the two tests was only in the size of the regions that were candidates for class reassignment. The first of these two conservative tests were for regions with only an isolated pixel whose class was different from surrounding pixels. The second test used regions two pixels or less in size. The single-pixel test filtered 3.94 percent of the pixels from the TM band 3, 4, and 5 classification result and had little visual impact. The two-pixel test filtered 14.91 percent of the pixels in the test site and gave a much more visually appealing classification map. Classification performance is discussed later in this report.

Accuracy Estimation

An NBSM scientist suspected that the registration of the ground truth data to the satellite data that was performed in Beijing might be off by as much as two pixels. Consequently, to allow for this two-pixel margin, the polygon outlines of the vector ground truth data were converted to raster format and transferred to LAS as a raster image file to mask out questionable areas during accuracy tests. A buffer zone two pixels wide on either side of each polygon boundary

Figure 14. An NBSM scientist comparing land cover categories between the cluster map and the ground truth map.

was created using the LAS SPREAD function. These potential misregistration buffer zones were then used to mask out all ground truth data in those regions so that only the central core of each ground truth polygon would be used when calculating accuracy. This process prevented the potential two-pixel misregistration from affecting the performance results. However, it also might have given an artificially high evaluation of performance because many of the actual edge, or transition, pixels were also excluded from contributing to the calculation of accuracy.

Because of the difficulty in uniquely identifying each cluster class with one of the 19 land use classes, both cluster and ground truth data were grouped into five land cover categories for comparison during the accuracy assessment portion of the project. These categories were water, forest, rice, urban, and other agriculture. Figure 14 shows an NBSM scientist comparing cluster map and land cover map categories.

Table 2 lists the ground truth land cover classes and the categories they were assigned. Table 3 details each of the TM and SPOT cluster classes and the land cover information class to which each cluster class was assigned. Tables 4-8 are contingency tables for the six classification vs. ground truth comparisons. NBSM staff evaluated these tables after their March 1989 working session at the EDC.

Accuracy Assessment

Tests showed that the overall accuracy of the classifications was slightly better than 50 percent. The cause of the rather low accuracy was probably because, in China, individual fields are small but grow a large variety of crops. This cropping pattern results in many individual pixels that represent a mixture of crops, making it difficult to generate cluster classes to identify a single crop.

Table 2. Ground truth land cover classes compared with the final accuracy categories used for each of the classification results.

Original data Pixel value & name	Accuracy Category value & name
11 Irrigated Rice	3 Rice
12 Dryland Agriculture	5 Other Agric
13 Irrigated Agriculture	5 Other Agric
21 Fruit Trees	5 Other Agric
22 Mulberry Trees	5 Other Agric
23 Tea	5 Other Agric
24 Rubber Trees	5 Other Agric
31 Forest	2 Forest
32 Brush/Shrubs	5 Other Agric
33 Sparse Forest	5 Other Agric
41 Natural Grasslands	5 Other Agric
51 Cities & Towns	4 Urban
52 Rural Residential	4 Urban
53 Industrial	4 Urban
62 Highways	5 Other Agric
71 Rivers	1 Water
72 Ponds & Reservoirs	1 Water
81 Mud Flats	5 Other Agric
99 Miscellaneous	5 Other Agric

Table 3. The six original classifications grouped into ten land cover information classes.

Original Classification	Land Cover Information Classes									
	1	2	3	4	5	6	7	8	9	10
TM bands 2,3,4 small site (19 classes)	1 2 3	5 16	17 18	4 6	10 11 19	8	9	7 12	14	13 15
TM bands 3,4,5 small site (29 classes)	1 2 3 4	6 7 8 11	20 21 27	5 9 10 14	26 28 29	22	12 13 15 24	23 25	16 17 18	19
TM bands 1,2,3,4, 5, 7, small site (36 classes)	1 2 3 4 7 8 9	10 11 12 30	31 32	5 6 13 14 19 20	25 34 35 36	16 33	15 17 21 23	18 24 26 28	22 27	29
TM principal components (36 classes)	30 33 35 36	25 28 29	3 5 6 7 22 21	18 19 20 31 32 34	1 2 4 8 9 10	15 23	16 26 27	12 17 24	11 14	13
TM large area study site (36 classes)	1 2 3 4 5	7 8 9	22 23 28	6 11 12 16	25 26 27 29 31	24	10 13 21	14 15 17 18 30 32	19 20 35	33 34 36
SPOT bands 1,2,3 small study site (28 classes)	1 2 3	6 13	14 15 16	4 5 7 8	18 19 20 22	10 17	11 21	9 12 23 24	25 26	27 28

Table 4. Contingency table for TM bands 2, 3, and 4 classification results.

	Ground Truth Categories					
Test Category	Water	Forest	Rice	Urban	Other agric	Total
Water	4,026	2,716	3,640	758	3,944	15,084
Forest	2,278	38,743	23,248	512	36,277	101,058
Rice	6,360	22,827	103,284	1,358	55,248	189,077
Urban	739	958	374	3,101	4,509	9,681
Other agric	3,695	23,212	28,813	1,358	83,581	140,659
Masked pixels	1,252	4,361	10,303	452	12,753	29,121
Total	18,350	92,817	169,662	7,539	196,312	484,680

$$\frac{228{,}709 \text{ correctly classified}}{455{,}559 \text{ total test pixels}} = 50.204\% \text{ correct}$$

Table 5. Contingency table for TM bands 3, 4, and 5 classification results with five ground truth categories.

	Ground Truth Categories					
Test Category	Water	Forest	Rice	Urban	Other agric	Total
Water	4,294	3,213	4,009	961	2,607	15,084
Forest	2,548	44,502	25,335	1,198	27,475	101,058
Rice	7,262	29,041	116,385	2,787	33,602	189,077
Urban	608	955	427	4,167	3,524	9,681
Other agric	4,117	31,314	31,789	3,133	70,306	140,659
Masked pixels	1,341	5,459	11,774	695	9,852	29,121
Total	20,170	114,484	189,719	12,941	147,366	484,680

239,654 correctly classified
455,559 total test pixels = 52.606% correct

Table 6. Contingency table for TM bands 3, 4, and 5 classification results, which were refined using nominal filtering (two-pixel region refinement), with five ground truth categories.

	Ground Truth Categories					
Test Category	Water	Forest	Rice	Urban	Other agric	Total
Water	4,293	3,071	4,223	921	2,576	15,084
Forest	2,426	45,277	25,656	1,019	26,680	101,058
Rice	7,081	27,771	119,593	2,600	32,032	189,077
Urban	590	900	423	4,268	3,500	9,681
Other agric	4,188	30,987	32,717	2,775	69,992	140,659
Masked pixels	1,368	5,321	12,060	675	9,697	29,121
Total	19,946	113,327	194,672	12,258	144,477	484,680

243,423 correctly classified
455,559 total test pixels = 53.434% correct

Table 7. Contingency table for TM bands 1, 2, 3, 4, 5, and 7 classification results with five ground truth categories.

	Ground Truth Categories					
Test Category	Water	Forest	Rice	Urban	Other agric	Total
Water	4,571	3,236	3,154	806	3,317	15,084
Forest	3,549	51,318	15,021	384	30,786	101,058
Rice	9,979	38,830	101,280	1,235	37,753	189,077
Urban	826	472	277	2,929	5,177	9,681
Other agric	5,867	34,647	21,641	1,054	77,450	140,659
Masked pixels	1,715	6,614	9,571	323	10,898	29,121
Total	26,507	135,117	150,944	6,731	165,381	484,680

$\frac{\text{237,548 correctly classified}}{\text{455,559 total test pixels}} = 52.144\%$ correct

Table 8. Contingency table for TM principal components classification using the first two components of the six calculated with five ground truth categories.

	Ground Truth Categories					
Test Category	Water	Forest	Rice	Urban	Other agric	Total
Water	4,349	1,654	4,314	1,103	3,664	15,084
Forest	3,307	27,821	30,844	773	38,313	101,058
Rice	8,583	16,381	120,784	2,670	40,659	189,077
Urban	505	140	504	4,798	3,734	9,681
Other agric	5,032	13,133	38,772	2,853	80,869	140,659
Masked pixels	1,570	2,937	12,491	860	11,263	29,121
Total	23,346	62,066	207,709	13,057	178,502	484,680

$\frac{\text{238,621 correctly classified}}{\text{455,559 total test pixels}} = 52.380\%$ correct

Difficulty in spectral classification also arises because different crops may have the same band-for-band spectral signature. It is also possible that the same crop has different spectral signatures because of differences in planting dates, water availability, and so on. Because classification assumes unique spectral signatures for the desired classes, the above conditions limit the accuracy achieved.

An examination of the results of the various TM classifications showed that the 2, 3, and 4 band combination had a lower accuracy than the 3, 4, and 5 band combination. This result was because bands 2 and 3 tend to be highly correlated and do not provide as much information for classification. The combination of bands 1, 2, 3, 4, 5 and 7 also resulted in a lower accuracy than the 3, 4, and 5 band combination. This result was probably because of the high correlation of bands 2 and 3, as previously mentioned, and of bands 5 and 7. The combination of bands 3, 4, and 5 appears to be the best for classification. Normal filtering techniques also resulted in some improvement in the classification accuracy. This procedure allows the analyst to control the merging of individual or small clusters of pixels into the appropriate cluster class.

The final step in the classification investigation was to calculate the similarity between each of the classification results using the S statistical package on a Sun workstation. This process was done using the five land cover categories to generate contingency tables and to calculate the $\hat{K}$ statistic (Cohen, 1960). The detailed $\hat{K}$ statistics are shown in table 9. In summary, each of the six classification results are different from one another.

Table 9. Correlation of $\hat{K}$ statistics for each classification result, to ground truth calculated using the S statistical package. [Note that each classification result is significantly different from the others].

Classification	$\hat{K}$	V	VO
SPOT 123	0.3733417	4.71506E-6	4.062468E-6
TM 345 Nomfil	0.3354755	5.29683E-6	4.376745E-6
TM 123457	0.3300715	5.055506E-6	4.19341E-6
TM 345	0.3254116	5.27819E-6	4.34815E-6
TM PC1&2	0.3080216	5.325085E-6	4.38511E-6
TM 234	0.2919653	5.352671E-6	4.40996E-6

The magnitude of the V and V0 values indicate, respectively, that each of the classification results is significantly different from the others (V) and that these differences can not be attributed to random occurrences (V0). That is, using the same ISOCLASS parameters to calculate the spectral classes with the six different band sets, six significantly different classifications were derived.

Other Processing

DEM Derivatives

During the EDC team's visit to the NBSM in the third year of the Protocol there was significant interest in modeling the physiographic characteristics of the study area using DTM data and some of the techniques developed as part of the drainage research conducted by an EDC scientist. An NBSM scientist met with an EDC scientist during the visit to the EDC and discussed these techniques and how they might be used to identify local topographic flat areas in the study area that are upland highs rather than valley lowlands. The scientist processed the DTM data for a 545- by 840-pixel test area and generated a flow direction image wherein individual pixel values indicated the number of other pixels that "drained" to it and a level image that identified flat areas that had local "pits" removed from them. These images were recorded on tape for an NBSM scientist to study after returning to Beijing. It was expected that the flat uplands would be easily discernable because of their relatively low values. Consequently, these data then could be used to refine classification results where spectral classes similar to rice were misidentified in the drier uplands.

Because rice and dryland crops are combined in the same spectral class, DTM data were tested to determine if topographic position could be used to separate these spectrally similar crops. The DTM data did not clearly distinguish the slope differences between the flat rice cropland and the flatter areas of the hilltops. Perhaps a combination of slope determinations as well as elevation differences would provide criteria for their separation.

Data Transformations

Principal Components Analysis

In addition to the classification studies, an NBSM scientist used the personal computer assigned to the project to generate principal component images from the six bands of TM data. He determined that the first two components that were calculated contained the most spectral information. This effort was done to build a smaller hybrid data set for processing on the smaller NBSM PRIME minicomputer to preserve as much of the spectral information as possible and, subsequently, to assess its performance as a proxy data subset for classification purposes. Figure 15 shows an image of the first principal component.

Texture Analysis

The NBSM team at the EDC also investigated use of image texture measures with the LAS TEXTURE function to calculate energy (second moment) and variance. Initial

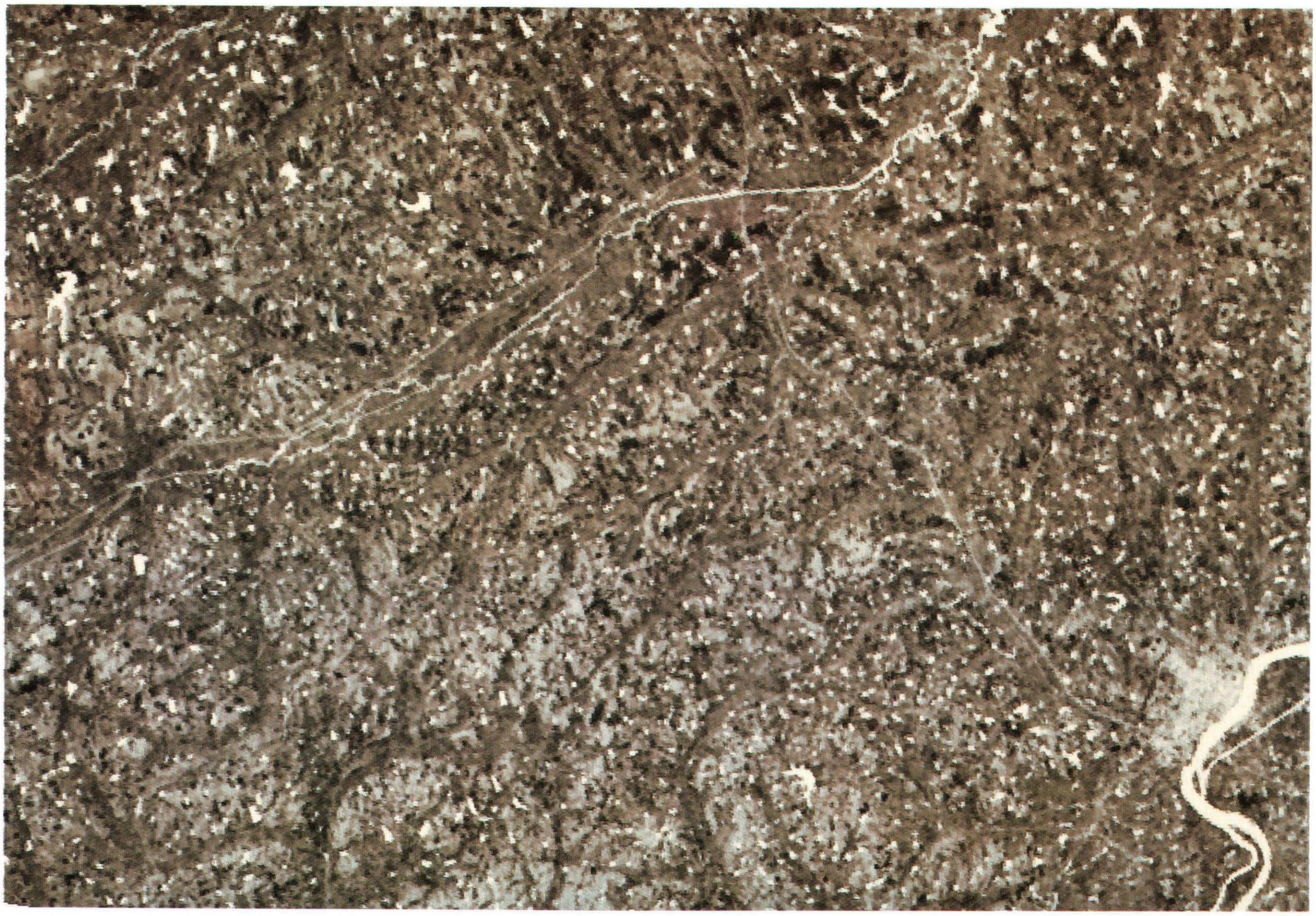

Figure 15. Image of principal component one resulting from the processing of the six bands of TM data.

results indicated that the energy measurement maintains image structure while emphasizing the low texture rice areas. Variance appeared to be similar to gradient or edge enhancement results and, therefore, would not be a useful measure of texture for post-classification refinement in terms of information class differentiation.

Beijing TM/SPOT Image Merge

To experiment with multisensor image merging techniques, the NBSM provided both SPOT panchromatic data and TM data over Beijing. The SPOT scene was registered to a map base and served as the reference for the TM image-to-image registration. The two scenes were merged using HIS techniques. The resulting scenes were enhanced and then printed as 1:50,000- and 1:100,000-scale photographs. Figure 16 shows the resulting image.

CONCLUSIONS

Evaluation of Products

Through this cooperative work, image maps and land use maps were produced from satellite data. Two 1:50,000-scale maps of the Ningxiang test site, overlain with 10,000-meter grid lines and principal geographic place-names, were completed. Satellite image mosaics of the Black Hills study area in the US were produced at scales of 1:100,000 and 1:250,000. A 1:100,000-scale image map of the Rapid City quadrangle was also produced using TM data.

The Rapid City image map was a new product that combined satellite imagery and linework on the same map. The traditional line map was printed on the reverse side of the image map to provide the basic map information. The satellite image background of the image map provides visual information about the land surface that is extremely helpful in the interpretation of the map. Even though the TM image is of lower resolution than the aerial photographs, it can meet the requirements of 1:100,000-scale maps of China. The added image processing that was used to produce the image map improved the overall quality of the images used.

Land use maps of the Ningxiang test site were produced showing that Level I land use categories could be defined. In some cases Level II categories were also defined. These maps can meet the demand for 1:100,000-scale land

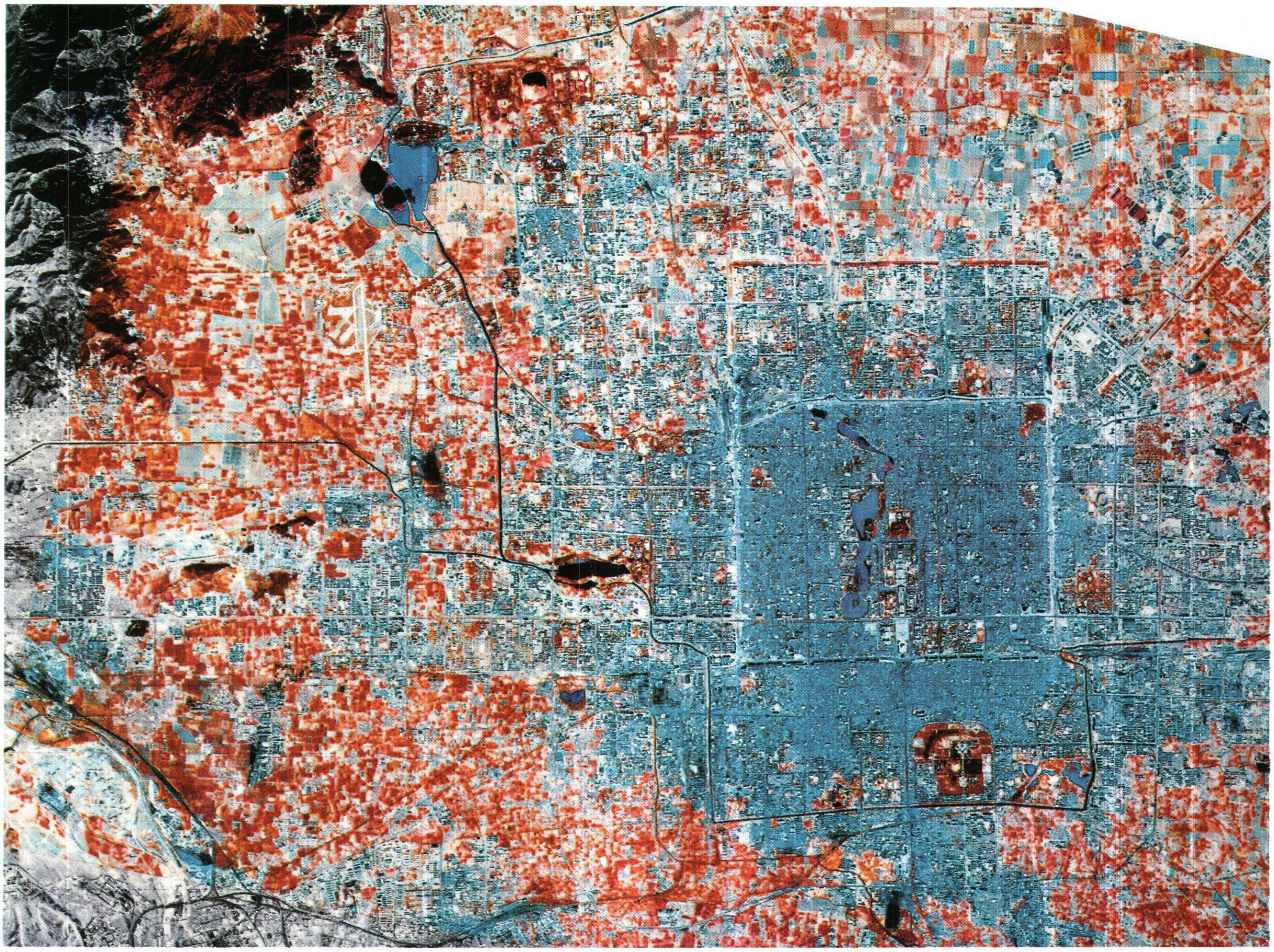

Figure 16. Image of Beijing resulting from the TM/SPOT merge and enhancement.

use maps of China. Because China is a country of vast territories and a large population, the importance of low-cost and rapid production of maps is vital to their resource investigations and land planning processes. Of added importance is the ability to frequently produce these maps to determine changes in land use.

Benefits of the Technical Exchange

Through the technical exchange described in this report, many of the key problems and technical processes involved in the production of satellite image maps and land use maps were resolved. Scientists from the NBSM were exposed to many advanced techniques in image processing and were able to put many of these techniques into practice. The investigations gave the USGS scientists a better understanding of how to apply image processing techniques to the rather unique geography of China. The small fields and complex cropping patterns of the land cover pointed out the need for further improvements in image processing techniques.

These cooperative experiments also led to decisions about the best approaches to land use mapping by showing the effects of different processing methods on classification results, the optimum TM band combinations to use, and the benefit of using ancillary data for improving classification accuracy. Perhaps most importantly, this cooperation strengthened the friendship and understanding of the mutual problems faced by scientists of both countries.

Technical publications (Lauer and Chu, 1988, and Qiu and Len, 1990) were generated as a result of the exchange. These publications further enhanced the relationship between the two countries.

SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

This cooperative effort was successful in applying remote sensing techniques to surveying and mapping and in promoting further development of such techniques. The US and the PRC agreed that the scientific and technical cooperation should continue for an additional 5 years with the following objectives:

1. Evaluate, and adopt where appropriate, standards for data processing, common data processing flows, and new data analysis techniques.
2. Investigate methods for exchanging, processing, and analyzing Landsat data, 1-km resolution Metsat data, and data from other satellite systems that can be integrated with other types of spatial data.
3. Conduct joint research on software development for thematic mapping, GIS integration, and change detection.

We look forward to continuing the research that was so successfully conducted in the previous term of the Protocol.

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