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Strategic Intelligence from ERTS? An Analysis of Digital Data on Soviet ICBM Sites

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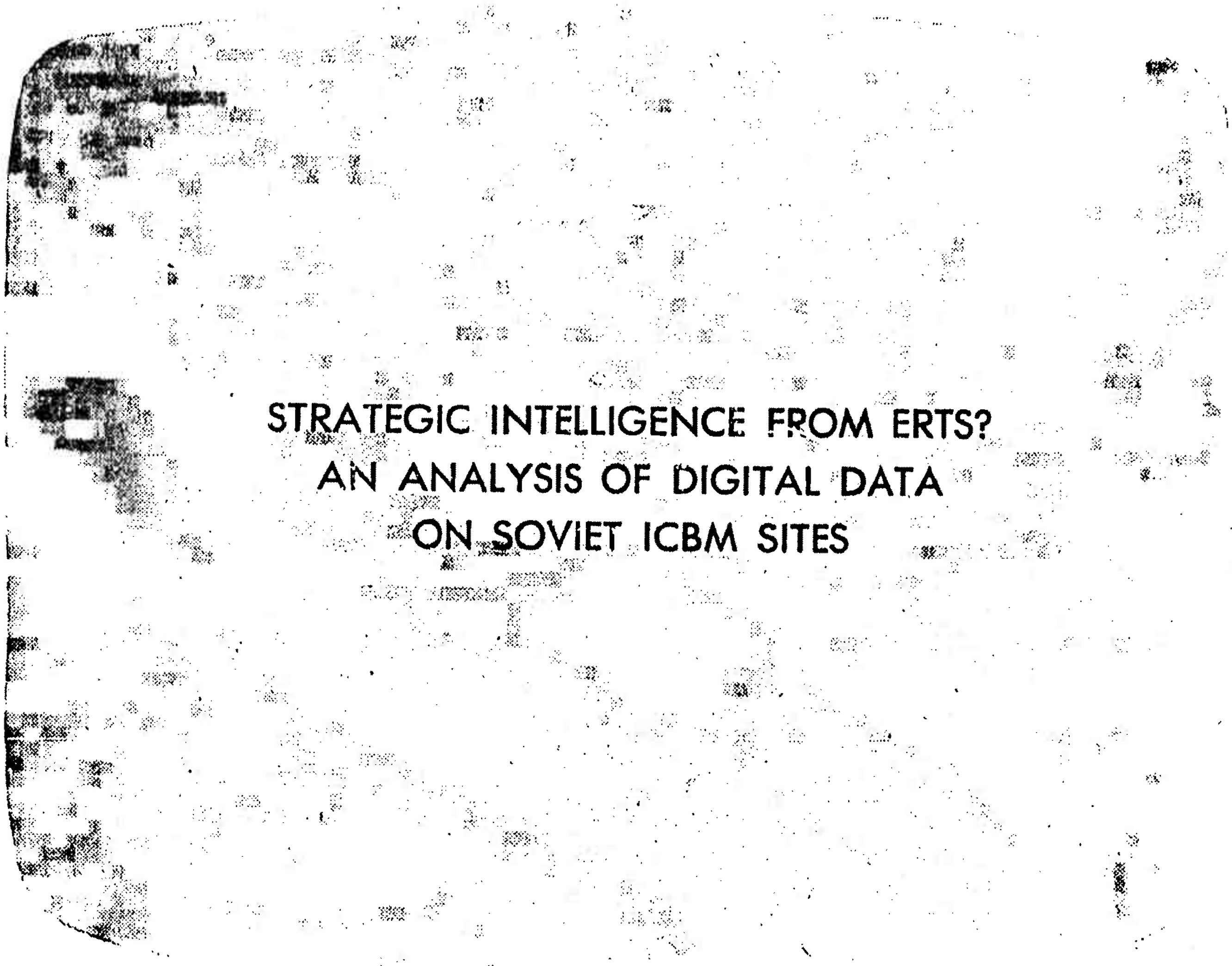

STRATEGIC INTELLIGENCE FROM ERTS? AN ANALYSIS OF DIGITAL DATA ON SOVIET ICBM SITES

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SUMMARY

The Earth Resources Technology Satellite, ERTS-1 (recently renamed LANDSAT-1), and its successor, LANDSAT-2, are providing the world with a revolutionary form of electro-optical overhead imagery at very low cost to the consumer. ERTS products are freely available for purchase from the United States, and a growing number of countries are building their own ground receiving stations.

ERTS data could be a source of strategic intelligence for countries that do not have access to overhead reconnaissance systems but do have strategic missile-targeting and other military requirements. Because of the growing usage of ERTS data and de-centralization of dissemination centers, the difficulty of detecting foreign military intelligence use of that data is increasing rapidly. This study reveals little evidence that foreign countries are exploiting the military and strategic intelligence potential of purchased ERTS data; but the Peoples Republic of China, which has shown interest in ERTS data and has made a considerable effort to obtain geodetic information and maps covering the Soviet Union and other areas, appears to be a possible user of ERTS data for such applications.

An assessment of standard ERTS multi-spectral film coverage of selected Soviet areas indicates that the Chinese could now use it to identify and target large cities, airports, port facilities, and transportation routes. ERTS digital images and data, supplemented by collateral information, could be used to map and target even smaller features, such as the larger Soviet SAM sites and soft ICBM sites. These applications would be particularly useful to the PRC for that part of the USSR within several hundred kilometers of the Sino-Soviet border, an area vitally important to the Chinese, where few other sources of geodetic information are available. Even the ERTS digital data has insufficient "resolution," however, for targeting hard Soviet ICBM sites.

In retrospect, it is clear that there was no way to precisely predict the full information value of the ERTS MSS data. This experience, coupled with the wide range of exotic remote sensors now under development, suggests that the military identification and mapping capabilities of each new unclassified satellite/sensor combination should be thoroughly evaluated.

NOTE—This research paper was prepared by the Office of Geographic and Cartographic Research. Technical assistance was provided by the Office of Research and Development and the National Photographic Interpretation Center. Technical data relative to mapping and certain other aspects of ERTS were taken from reports of the U.S. Geological Survey (EROS Program Cartography Office). The paper was coordinated with offices of the Directorate for Intelligence and the Directorate for Science and Technology. Comments and questions may be directed to [redacted] Code 143, Extension 2706, or [redacted] Code 143, Extension 3508.

STRATEGIC INTELLIGENCE FROM ERTS? AN ANALYSIS OF DIGITAL DATA ON SOVIET ICBM SITES

INTRODUCTION

World-wide satellite imagery for intelligence and earth resource studies was routinely available to only a select group of countries until the Earth Resources Technology Satellite (ERTS-1) was launched on 23 July 1972. Since that time, the Earth Resources Observation Systems (EROS) Data Center—operated by the U.S. Geological Survey in Sioux Falls, South Dakota—has been disseminating imagery and related products, generated over the entire land area of the world by the satellite, to any person or government able to pay the relatively inexpensive purchase price. The usefulness of ERTS-1 data for compiling information about the resource base of all countries has become apparent to governments and scholars around the world, and the capability for exploitation of the material is spreading.

The sensors of ERTS-1 were designed to be useful for gathering synoptic information over broad areas by recording large features such as fields, forests, and geological formations. Resolution was kept low primarily to optimize those applications. The low resolution was also generally expected to minimize the possibility that the data would be used for military intelligence purposes.*

The EROS Data Center provides data in the form of both film and digital-tape products. During the past year, it has become apparent that the digital-tape data provided by ERTS, when subjected to computer manipulation and display, contain information of a kind which has never before been available; furthermore, the digital images combining information from several spectral bands offer a visual resolution significantly better than that expected for the early standard film products.* In addition, the geometric fidelity of the film images has been found sufficient for medium-scale (1:500,000 and 1:250,000) mapping.

LANDSAT-2, with a sensor package similar to ERTS-1, was launched in mid-January 1975. Current plans for LANDSAT-C, the next in the series, include doubling the resolution of the Return Beam Vidicon Cameras (see below) to approximately 40 meters. The ERTS user community has continued to press for imagery with even higher resolution, with the result that a multi-spectral scanner having a theoretical resolution of approximately 10 meters has already been studied as one of a series of sensors that could be used in the 1980s in proposed follow-on systems such as NASA's Earth Observations Satellite (EOS).

These developments raise the possibility that earth resources satellite data may some day be used for missile targeting and related intelligence purposes by nations that do not have access to high-resolution satellite systems. The proliferation of nuclear weapons among nations currently with-

*The term "resolution" has a wide range of meanings. In the field of optics it has traditionally referred to the capability of the optical system to separate either point or standard bar targets; if a photo-interpreter could distinguish at best two 5-meter-wide bars separated by a distance of 5 meters, that photograph was described as having a 10-meter resolution. In the field of electro-optics, which is more relevant since ERTS is an electro-optical system, "resolution" commonly is equated with the size of the instantaneous field of view of the sensor detector. The ERTS Multi-Spectral Scanner imagery would have a resolution of 79 meters by the electro-optical definition and 221 to 332 meters by the optical definition. In reality, high-contrast linear features even narrower than 79 meters can be seen and in some cases identified on ERTS imagery. For this reason, remote-sensing specialists now talk in terms of "detectability" rather than "resolution" and in general avoid the use of the latter term.

*In reality, all ERTS imagery is "digital imagery." The standard film products that have been produced to date, however, have not retained all of the data from the tapes, and visual enhancement of the complete digital data on television screens has allowed much more flexibility in the identification of individual items. It is useful, therefore, to make a distinction between standard ERTS film products and the "digital images" displayed directly from the digital data.

out reconnaissance satellites and efforts by some of those nations to gather foreign maps and other locational information has prompted this re-evaluation of the potential of ERTS data for use by other countries as a source of strategic intelligence for missile targeting. This paper presents an analysis of what is currently the highest quality form of ERTS data—the computer-compatible digital tapes (CCT's) and images produced from them—in order to ascertain whether certain kinds of strategic targets, such as Soviet ICBM and SAM sites, can be identified therefrom and then mapped with sufficient accuracy for missile targeting.

Techniques employed in this analysis include visual comparison of ERTS film products and digital images with classified satellite photography for the purpose of locating missile sites; the use of digital computer overlay and classification procedures to discover similarities in the gray-scale values of the missile sites; and the use of ratio techniques to improve the accuracy of the classifications. Sequential data overlays, which appear to hold some promise for improving the information content of ERTS imagery, are not addressed, but should be further examined when the technique is perfected.

This analysis uses the Peoples Republic of China (PRC) as a case study of a country that could benefit by using ERTS data for strategic purposes. The PRC already possesses long-range missiles with nuclear warheads but does not yet have access to reconnaissance satellite photography for missile targeting and other military purposes; it has also expended great effort to obtain maps of areas—particularly in the USSR—against which its missiles are targeted. The relevance of the PRC example is of limited duration since Peking is expected to launch its own military reconnaissance satellite by the end of this decade. (As early as 1972 PRC representatives were in contact with U.S. firms to explore the purchase of camera systems which had been developed for U.S. satellites.) Nevertheless, the spread of missile and weaponry technology could stimulate additional countries to evaluate freely available ERTS data for military intelligence utility.*

*Appendix B examines available evidence related to PRC efforts to obtain ERTS data.

ERTS-1 SENSORS, PRODUCTS, AND ANALYTICAL POTENTIAL

ERTS-1 was launched with two sensor packages—the three-channel Return Beam Vidicon (RBV) camera system and a four-channel Multi-Spectral Scanner System (MSS). The RBV system uses three cameras to simultaneously record reflected solar energy in three spectral bands (.475-.575μm, .580-.680μm, and .698-.830μm) in analog format (electronic wave-forms).* The image is then transmitted in television fashion to ground receiving stations for ultimate conversion into film products. The MSS, which is sensitive in two visible (.500-.600μm and .600-.700μm) and two near-infrared (.700-.800μm and .800-1.100μm) bands, scans 79-meter cross-track swaths 185 km in length. The results of the scan are recorded in digital form, transmitted to the ground receiving stations, and then processed and converted at NASA facilities into both film products and computer-compatible digital tapes.

An electronic anomaly discovered in the satellite shortly after launch prevented the use of the RBV system after a few initial images had been produced. The MSS, though, enjoyed spectacular success in spite of a degenerative tape recorder malfunction that limited the amount of coverage of foreign areas. The tape recorder ceased to operate for all practical purposes on 2 July 1974. Since then, MSS data from ERTS-1 has been recoverable only for areas near direct-reading ground receiving stations in the United States (Goldstone, California; Greenbelt, Maryland; and Fairbanks, Alaska), Canada, and Brazil.

The film output from the RBV system was expected to be theoretically capable of distinguishing objects approximately 70 meters on a side, and the MSS was expected to distinguish objects approximately 80 meters on a side. The latter figure is

*The visible spectrum includes reflected solar energy in the range .380-.780μm wavelengths, while most panchromatic (black-and-white) aerial film is sensitive at wavelengths of .360-.720μm. NASA designated the RBV channels as 1, 2, and 3 in order of ascending wavelengths, and similarly numbered the MSS channels 4, 5, 6, and 7.

equivalent to the instantaneous field-of-view of the MSS sensor detector, which is represented on an ERTS image by a rectangular picture element, or "pixel." In theory, it takes three to four such pixels to visually separate objects on MSS imagery; consequently, the MSS should be able to resolve bar targets 200 to 300 meters wide. It is apparent to even the casual observer, however, that high-contrast linear targets of a considerably smaller size can be seen. Soon after the first products became available, academic, industrial, and government scientists began trying a variety of methods to enhance the standard MSS film products in the hope of maximizing the visual detail. Early efforts with the film enjoyed some minor successes. When scientists turned their attention to the computer-compatible tapes in mid-1973, a more significant increase in object detectability was obtained.

The complicated process through which digital images are obtained from the MSS data is described in Appendix A. In summary, each MSS frame, or scene, contains more than 7½ million pixels, each of which represents a 57- by 79-meter rectangle on the earth's surface. Each pixel is assigned a gray-scale value based on the intensity of reflected solar energy from that area on the ground, and the gray-scale values are then recorded by pixel location on a digital computer tape. This process occurs simultaneously in each spectral band. The tape is processed through a computer to reproduce an approximation of the original image on a television screen, and the images from all four bands can then be overlayed visually on a color television screen. This is approximately the manner in which the color-infrared image of Washington, D.C., was made (Figure 1). Images obtained in this fashion are not subject to any of the tonal errors which often result from variations in film processing and registration. They can be "enlarged" to any desired scale without worrying about film graininess—even to the point where individual pixels can be clearly seen (Figure 2).

These characteristics of the digital image provide certain advantages over conventional aerial photography. The eye can "see" or distinguish an average of only 16 shades of gray. Yet the ERTS scanner distinguishes 64 gray levels in each of the four spectral bands. It is obvious that there is much more information in an image of any one band than the eye can see. Furthermore, by overlaying bands the number of possible combinations of gray levels soars. A person looking at a color television screen can actually see some of this process taking place; the resolution appears to increase each time data from another band is added, yet he sees only a very small portion of the increase in selectivity that is actually occurring (Appendix A).

In order to take full advantage of these features of ERTS data, it is necessary to directly employ the numerical data on the digital tapes. The computer can rapidly locate individual pixels or clusters of pixels with specific numerical values in any one spectral band. It can also compare data for the same area from two or more spectral bands in order to determine whether there are distinct cross-band patterns in the combinations of numerical values for particular points. Known targets can be visually located on the digital image, and the pixel values for those locations can then be used as the criteria with which the computer can identify or "classify" features with similar signatures. For example, a scientist wishing to identify concrete wherever it appears on an ERTS image would first locate an area known to be concrete (e.g., a large concrete parking lot) and determine the range of values in each band which represented his sample. He could then direct the computer to identify every other pixel in the remainder of the ERTS frame where the same combination of values appeared. His chances of identifying concrete would increase each time he added data from an additional spectral band.

The scientist in this hypothetical example probably would not be able to determine visually whether a bright return on the ERTS color-infrared composite film product represented concrete or asphalt or cleared ground, but the digital data would almost certainly be able to separate the three and help him determine which he was seeing. Thus the "resolution" or "detectability" concepts associated with optical systems cannot be considered complete measures of the potential of ERTS and other electro-optical data for identification of objects; there is more to ERTS than meets the eye, and the digital numbers game must be played as well if the true potential of ERTS is to be realized.

CONTROL OVER ERTS DATA

All ERTS data are currently available to everyone through the EROS Data Center in Sioux Falls, South Dakota, and are becoming available through other government centers. Imagery products are quite inexpensive, and the cost of the digital tapes—$240 per scene—is not prohibitive. Few digital tapes, especially of foreign areas, have been purchased so far relative to the total volume of business. Records of sales through these data centers could provide a limited opportunity to monitor routine acquisitions of data by foreign purchasers.

LANDSAT operations are controlled and monitored by the NASA Command Center at Goddard Space Flight Center in Greenbelt, Maryland. Command signals to the satellite are not encrypted, but the coding is sufficiently complex to prevent random activation. The command signal to start operations could be covertly generated, but that would require a sophisticated ELINT or other clandestine effort to obtain the code. NASA officials would know if clandestine activation had occurred by evidence of an unscheduled drain on the satellite's power supply.

There are now two active foreign-controlled ground receiving stations for ERTS data—in Canada and Brazil—and another under construction in Italy. Many other countries have contracted for or are considering acquiring one. Under present procedures such countries would have the capability to receive direct transmissions from the satellite only while it is active within range of their receiving stations. Data can be acquired over areas of neighboring countries within a radius of about 1,500 to 2,500 kilometers from the ground station, but only when NASA places the satellite in direct-transmission mode. In the event of failure of the U.S. tape recorder read-out facility, one of these stations would be provided the necessary command signals and asked to temporarily receive the world-wide data stored in the satellite's tape recorder.

Each country having a station is requir[illegible] o enter into an agreement with NASA to ensu[illegible] the data they acquire is available for sale to [illegible] one. Canada's ground station does not routi[illegible] acquire data over the United States. Brazil, whi[illegible] has taken a strong stand against ERTS data acquisition without prior approval of the country being sensed, nevertheless has offered to acquire—and is obliged to sell—ERTS imagery of countries within range of its ground receiving station. Italy and Iran have also indicated that they would like to operate as regional acquisition and dissemination centers. There will be no practical way for the United States to monitor dissemination from these facilities, which are expected to eventually account for a significant portion of total ERTS usage.

Nations planning to use ERTS data for intelligence purposes would probably attempt to protect their intelligence sources and goals by purchasing it through an intermediary or acquiring a covert ERTS receiving capability. Appendix B discusses an apparent example of the former method; the latter is much less likely to occur because of the cost involved, because of NASA's control of direct transmissions of data from the satellite, and because an ERTS ground receiving station could be acquired openly for scientific purposes.

IDENTIFICATION OF STRATEGIC FACILITIES WITH ERTS DATA: THE SOVIET EXAMPLE

The first intelligence community experiments to determine whether strategic intelligence could be derived from ERTS imagery dealt primarily with film products and led to the conclusion that ERTS was useful to countries without sophisticated reconnaissance programs only for locating major cities, airfields, and transportation routes. Subsequent developments in processing digital imagery and basic digital tape data suggested that strategic targets much smaller than airfields could be located and even identified using new techniques. Examination of some digital imagery of Washington, D.C., for example (Figures 2 and 3), shows that the monument on Roosevelt Island—a complex structure composed of brick and marble statuary, clay walkways, water ponds, concrete slabs, and bronze plaques—affects two pixels, which are clearly distinguishable from those representing the surrounding area, even though the monument is only [illegible]4 meters in diameter.

To determine whether the ERTS data was significant for location of strategic targets, investigators examined the most important and difficult-to-find strategic targets—hardened ICBM launch sites—in a variety of surroundings and surveyed larger targets (SAM sites, etc.) nearby. Because the four complexes selected are widely separated, investigators were able to examine variations caused by a wide range of environmental conditions—including snow cover.

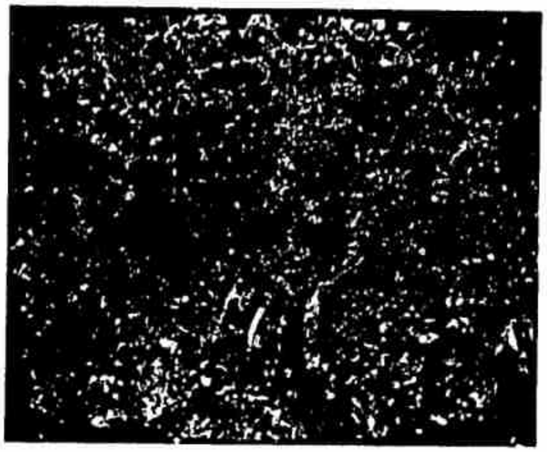

Figure 1. The color-infrared composite digital image of bands 4, 5, and 7 is comparable to a color-infrared photograph of the Washington, D.C. area. The clarity and interpretability of this image is remarkable when compared with the standard ERTS film product.

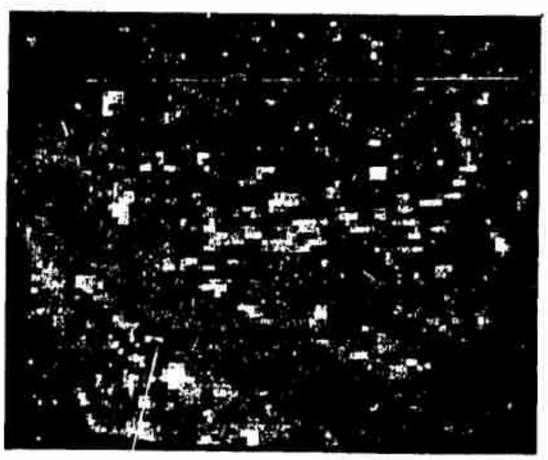

Figure 2. This "magnification" of Figure 1 was accomplished by repeating the value of each pixel (picture element) six times in both the *x* and *y* directions. As a result, the blocky appearance of the pixels is visible. The pixels representing the 94-meter-wide Roosevelt Island monument are circled.

Figure 3. The image appearing here was obtained by modifying each of the values in the 6-x-6 matrix composing a pixel in Figure 2 by a *Sin x/x* function. The monument on Roosevelt Island assumes a more natural shape, the 14th Street bridges become more "visible," and the Washington Monument and its 9:30 a.m. shadow can be seen.

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For the experiment, areas in the [redacted] ICBM complexes were used to provide a large number of Type IIID ICBM sites (Figure 4).* The Type IIID site normally consists of a 67- by 11-meter concrete apron; a homeplate-shaped silo cover, usually located near the center of the loading apron; a small security building; a small bunker; and at least two security fences surrounding the site. In addition, a concrete or gravel T-shaped turnaround is frequently attached to one end of the pad for the convenience of the missile transporters. 25X1D

The sites were first pinpointed on classified satellite photography and then located on ERTS imagery. Because of the problems involved in trying to identify the numerical signatures of all

*Type IIID sites are the sites most commonly encountered in the Soviet Union, and the concrete area involved is generally smaller than that of any other fixed-location ICBM site. Identification of other hardened sites with larger concrete areas (e.g., the Type IIIC) was not addressed because of the lack of ERTS data over areas having large numbers of such sites, and because the decision to target ICBM sites would eventually necessitate targeting *all* ICBM sites, including the most difficult to find.

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the different materials found at a missile site (e.g., gravel, fence wire), the investigators concentrated on the concrete pad and attempted to identify the pixel or pixels in which it was located. In all, 83 missile-site aprons, covering a total of 162 pixels, were located in the four sample areas. (See Appendix A for detailed procedures.)

It was possible to visually locate the concrete aprons within one to four pixels of Band 5 imagery when classified reference photography from approximately the same time of year was available. However, no special visual signature related to the ICBM sites could be found on the ERTS imagery because the area of the average Type IIID site is simply too small relative to pixel size. Moreover, a multitude of other pixels appeared to have the same brightness values as the pixels for the missile sites.

The first steps in the digital analysis confirmed these preliminary findings. A comparison of the missile-site data with the overall distribution of gray-scale values in each of the four sample areas showed that single-band ERTS data could not be used in any situation to isolate the Type IIID sites; the range of values was too wide, and the number of non-missile-site pixels with the same value as any one missile-site pi. el was far too large to permit the use of digital identification procedures (Appendix A, Foldout A-1). Some features of the distribution of data, however, suggested that simultaneous multi-band digital analysis of each frame might hold some promise.

The General Electric Image 100, an interactive mini-computer system which permits simultaneous digital and visual analysis, was used to examine whether four-band digital signatures of the missile sites were unique and to determine how other pixels with identical digital signatures were distributed in each scene (Appendix A). The digital signature for each missile-site pixel alarmed an average of 60 other pixels which were not located on missile sites, a relatively small number in consideration of the total number of pixels in the ERTS sample area—but still too large to permit the use of digital identification procedures alone for isolation of the missile sites. A wide range of ratio and other statistical techniques were also used on these data sets with the aid of the Image 100, but they were of little help in reducing the error factor (Appendix A). Furthermore, test results showed conclusively that, at the resolution of ERTS-1 and LANDSAT-2, it would be impossible to use a general classification scheme (one dependent upon *ranges* of values in each band) to locate and positively identify Soviet Type IIID missile sites, even with the aid of supplementary data.

While the result of digital analysis using existing materials and techniques was, for all practical purposes, negative insofar as the identification of hardened ICBM sites is concerned, the exercise clearly showed that the same techniques, utilizing material with reduced pixel size, would probably have a much better chance of success. Government, industrial, and academic scientists are currently attempting to achieve at least a twofold reduction in effective pixel size by overlaying both visual and digital data sets from sequential ERTS passes over the same area. The precise procedure and registration techniques are still under development. The only other way in which pixel size could be reduced would be through the use of a new MSS with a smaller instantaneous field of view, and no such digital sensor is planned for LANDSAT-C.

Visual analysis of larger strategic targets on digital imagery, which was carried on simultaneously with the digital analysis in this experiment, proved more successful. Installations like the older Type IIB ICBM launch sites and support facilities and SA-5 surface-to-air missile sites displayed a visual pattern on ERTS digital imagery that was consistent with known Soviet military installation signatures (Figures 5, 6, 7, and 8). Some advance knowledge to supplement the ERTS data (e.g., defector reports or observations from automobiles and commerical aircraft) would probably lead to identification of major military installations. Recent U.S. press articles on Tyuratam and Plesetsk show that knowledge of the approximate location of major facilities can lead to some correct interpretations of functional areas within such installations, even with standard ERTS film images. ERTS digital imagery used in this experiment shows that use of specially processed ERTS data significantly improves the chance of correctely identifying and locating strategic targets larger in size than single ICBM silos, and the initial intelligence community assessment that ERTS imagery is useful only for identification of large cities, port complexes, and airfields must consequently be applied only to standard ERTS film products.

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[redacted]

Figure 6. This color-infrared composite ERTS digital image of bands 4, 5, and 7 of the same area as Figure 5 shows that the SA-5 site signature is clearly discernible, while the SA-2 site, which is much smaller and has a less distinctive signature, is not. The Type IIID site leaves a bright trace, but there is no possible way to identify it without the aid of classified photography. This image was deliberately scale- and azimuth-distorted to obtain the maximum sample area in the frame.

GEODETIC AND CARTOGRAPHIC APPLICATIONS

Although the main purpose of an ERTS-type satellite, with its repetitive coverage, is to provide data for analysis of dynamic phenomena on the earth's surface, ERTS imagery is also suitable for limited cartographic and geodetic applications. A number of U.S. and foreign organizations have undertaken substantial mapping programs using ERTS data to update existing maps and as the cartographic base for new maps.

Civil mapping experiences suggest that there are also potential military mapping applications. For example, nations that lack their own reconnaissance satellites could produce maps of denied areas of potential adversaries—particularly important for those such as the USSR that tightly control medium- and large-scale topographic maps.

Experiments to date have shown that individual ERTS images can be joined, or mosaicked, to form photomaps that meet U.S. National Map Accuracy Standards (NMAS) for horizontal positioning at the 1:1,000,000 and 1:500,000 scales. More limited tests indicate that 1:250,000 photomaps in the format of individual frames can be produced that meet or exceed the NMAS standard equivalent to 80 meters (rms) for horizontal positioning.

Maps produced from ERTS imagery to cover a denied area (e.g., PRC navigation or air target charts of the Soviet border area) would lack the detailed cultural information and elevation data that would be useful for many purposes. Inability to perform ground checking would limit map content to details that are visible on the imagery, either independently or with the assistance of

25X1D

[redacted]

Figure 7. This classified satellite photograph of a sample area in the Kostroma ICBM field shows the signature of a Type IIB soft ICBM launch site and support facility.

Figure 8. The ERTS color-infrared composite of the area in Figure 7 shows that the Type IIB launch site and support facility are identifiable as military installations partly because of their isolation in the red-toned forest area, their shape, and the pattern of the roads leading to them. Identification of Type IIB sites, whether in the same setting or in other surroundings, would be impossible without some collateral information, and there is no assurance that Type IIB sites could be identified with any consistency for the whole Soviet Union. In any event, an interpreter would be hard-pressed to differentiate between the launch site and the support facility without substantial collateral information.

collateral information on the area. Nevertheless, maps such as this would probably be far superior to those now available to the PRC and would be extremely valuable for planning or conducting military operations against the USSR. One example of the high value the PRC places on maps of the USSR was its offer several years ago of $5,000 for each of the hundreds of US- or USSR-produced topographic sheets along their border zone.*

Geodetic coordinates of photoidentifiable targets could also be obtained to improve the targeting capability of missile systems. The accuracy of target positioning using ERTS images varies widely, depending on the image products used and on the availability of additional data over the area covered by the imagery.*

In the worst case, using only bulk-processed ERTS imagery and no supplementary geodetic or cartographic materials, identifiable points can be located from the coordinates printed on the image itself to an accuracy of 2,000 to 5,000 meters. At the other extreme, possession of good geodetic data or maps over the area of the image allows identification of image distortion patterns and location of identifiable ground points on either RBV or MSS imagery to within 50 to 100 meters.

*PRC map collection efforts are described further in Appendix B.

*Geodetic positioning techniques and their contribution to missile accuracies are detailed in Appendix C.

The accuracy with which the PRC could locate points in the USSR would fall between the above values, depending on the location in the USSR and the availability of U.S. and Soviet maps of the area. Other than for areas where good maps may have been acquired, the best positioning capability exists for the area within a few hundred kilometers of the Chinese border. Within this zone the PRC could extend its local geodetic control into the USSR through contiguous ERTS scenes to locate Soviet positions with errors ranging from less than 100 meters near the border to more than 200 meters at distances of several hundred kilometers from China. For USSR areas farther from China, maximum error limits of 2,000 to 5,000 meters could be reduced by position-correcting the ERTS scenes with several U.S. map series that have internal errors ranging from 200 to more than 1,400 meters.

The geodetic positioning data that ERTS can provide would not necessarily improve PRC ballistic missile accuracies against all potential targets. This is particularly true at present when the operational PRC ballistic missiles are estimated to have an average miss-distance or circular error probable (CEP) of 2 kilometers or more and are therefore suitable for use only against soft targets such as urban complexes. It is believed that for at least the next several years the limitations in number and accuracy of PRC missiles will preclude their use as counterforce weapons against individual missile sites.

For the United States and South and East Asia, good quality local maps that would enable the PRC to locate potential targets to within a few hundred meters are readily available. This level of positioning accuracy is believed to be adequate to meet their current requirements.

The PRC's missile-targeting problem against the USSR is quite different. Not only are some potential target complexes *not* shown on available maps, but urban areas that are shown may be in error by many kilometers on Soviet maps and by several hundred to more than 1,400 meters on US maps. Use of ERTS in combination with these maps would reduce the target position factor to a scale that would be more consistent with the other error elements that contribute to the total PRC missile system CEP.

CONCLUSIONS

ERTS-1 has provided the world with a revolutionary form of imagery; the multi-band character of ERTS data permits the use of a wide variety of new techniques to identify features that have been imaged by the system.

ERTS film and digital products are, to some extent, useful sources of military intelligence for countries that lack basic elements of information necessary for targeting. Because of the relatively high degree of geometric fidelity in the MSS images, they can also be used to determine the approximate horizontal coordinates of identifiable features and to make and revise small- and medium-scale maps.

ERTS products presently available offer a range of capabilities. The standard 9- by 9-inch transparencies and similar film products can be used for the identification and mapping of large cities, airfields, port facilities, and transportation routes. Digital images can in some cases be used for the identification and mapping of smaller features, including Soviet SA-5 sites and soft ICBM sites, when other information is available to indicate their approximate location. Digital tape data also offers some promise of automated identification of those homogeneous-material facilities with similar configurations that are large enough to dominate the gray-scale values of several pixels.

ERTS data would be most useful for targeting purposes to countries that have nuclear weapons and delivery systems but no overhead reconnaissance capability or other sources of the required information, e.g., the PRC. Medium- or large-scale maps and supplemental information about geodetic control in the target area would, in conjunction with ERTS data, enable their analysts to locate the larger strategic targets.

The investigators found only limited indications that any particular foreign government may be using ERTS data as a source of strategic intelligence. Data control over the satellite has been sufficient to detect direct clandestine use, should it ever occur. There is now only a partial capability for monitoring routine foreign purchases of ERTS data, however, and the increasingly complex dissemination network and growing number of data users continually reduce the chances for ascertaining the uses of ERTS data sold to foreigners.

The PRC could use ERTS imagery in conjunction with available maps and other collateral information to improve its knowledge of targets in adjacent Soviet territory. Extensive PRC efforts to obtain maps and geodetic data confirm that Peking has a requirement for targeting materials. ERTS imagery would permit PRC experts to locate target positions within 100 to 200 meters (considerably better accuracy than is obtainable without the ERTS data) for a distance of about 100 miles into USSR territory. Farther inside the USSR, ERTS imagery together with available maps could be used to locate positions with sufficient accuracy for targeting missiles against such soft targets as urban complexes.

Even if the requirement existed, however, PRC targeting experts would not be able to use ERTS-1 data in any form to identify and locate Soviet Type IIID missile sites and target them, since the appearances of those sites on the imagery and their digital signatures vary too widely. Ground features which are smaller than pixel size cannot be identified by either visual or digital means and must be located by other methods.

If the parameters of future ERTS-type data change, the entire situation will have to be re-evaluated. Halving the pixel size, for example, might enable use of the MSS data to locate installations as small as the Soviet Type IIID ICBM sites. And untested sensors (including the RBV on LANDSAT-2) should be evaluated independently for this capability. The use of digital format on the MSS payload has clearly shown that the old methods of evaluating "resolution" of a sensor on the basis of bar targets simply do not apply to such data.

GLOSSARY

TERMS AND ABBREVIATIONS

CCT .... Computer-Compatible Tape—magnetic computer tape on which digital values representing the reflected solar radiation are recorded. Each ERTS frame fills four tapes.

CEP .... Circular Error Probable—average miss distance for a missile warhead, defined as the radius of a circle around a target within which there is a 50 percent probability of warhead impact.

Convolution .... Pre-processing of digital data to normalize the original data or to make the image more easily interpretable through either digital or visual procedures.

Digital Image .... An image displayed on a television screen, produced by assigning gray-scale values to the recorded levels of reflected solar radiation in each ERTS frame.

ERTS .... Earth Resources Technology Satellite—NASA-controlled electro-optical sensing satellite. The initial designations prior to launch were alphabetical (ERTS-A, B, and C) and after launch the suffixes were changed to numerical form (hence ERTS-1). NASA has only recently changed the name of this series to LANDSAT (land-satellite), and ERTS-B, launched in January 1975, is now known as LANDSAT-2.

Gray-scale .... A range of numerical values assigned to the visual tonal gradation from black to white. Higher numbers represent increasingly lighter tones.

Instantaneous Field of View The total area observed through the aperture of a sensor at any given instant.

Missile Error Budget ...... A list of weapons system and geodetic and gravitational error factors that contribute to missile impact errors.

MSS .... Multi-Spectral Scanner—an electro-optical remote-sensing system that simultaneously records reflected solar radiation in two or more distinct ranges of the electromagnetic spectrum.

Pixel	Picture Element—the smallest data block in an ERTS scene, representing the 79- by 79-meter area on the earth's surface observed by the ERTS MSS sensor at one instant. The size of the pixel in an ERTS image is reduced to 57 by 79 meters to retain scale fidelity.
Reflected Solar Energy	The electromagnetic radiation from the sun which is reflected from an object on the earth's surface. Every object also is a primary source of electromagnetic radiation, but the amount of such radiation is negligible in comparison with the amount of reflected solar energy observed by a sensor.
RBV	Return Beam Vidicon—a three-camera remote-sensing system on the ERTS satellites. Each camera, sensitive in a different spectral range, records a 185- by 185-km scene and transmits that image to earth in essentially the form of a television image.
Scan Line	A line, roughly perpendicular to the line of flight, along which the scanning sensor of the MSS moves.

APPENDIX A

Analytical Procedures Used on ERTS Digital Data from Soviet Missile Sites

The digital data under study here are obtained through a complicated process. Each 185-km-long scan line covers a strip on the earth's surface approximately 79 meters wide. The scanner continually observes an area 79 meters square as it moves along the scan line, and the average intensity of reflected solar energy for that field of view is recorded electronically every 57 meters. This electronic signal is converted to a digital value and then transmitted directly to the ground receiving station or recorded for later transmission. At the ground receiving station, the data are stored on high-density video tape, which must then be converted to computer-compatible digital tape.

The digital values are interpretable as gray-scale values—the basis for creating an image on a television screen. There are 64 such values in each spectral band. In creating a black and white image of one band, the numerically lowest value is traditionally assigned black and the remaining tones are lightened slightly with each increase in value. The majority of values fall within a small range (20 to 40 levels as opposed to 64), and the image is usually created by "contrast-stretching," assigning the black-to-white range of tones to a much smaller interval of values from the tape.

Each ERTS frame contains 2,340 scan lines, each of which is divided into 3,240 picture elements, or pixels. There are 7,581,600 pixels in a single-band image. Each pixel may be located by its x and y coordinates in the 3,240-by-2,340 matrix, which is slightly skewed along the North-South axis because of the inclination of the ERTS-1 orbit.

Because the radiation intensity for any one pixel is recorded on all four bands simultaneously from the same point in space, the pixel locations across the four bands are congruent. This allows the use of both visual and digital overlay techniques for comparison of data and the creation of composite images. For example, a color-infrared image can be created on a color television screen by assigning the values from bands 4, 5, and 7 respectively to each of the three color "guns" in the set (Figure 1, main text). The computer used in creating the image can also be used in most cases to analyze clusters of like digital data within any one spectral band or to compare data from several bands. Certain of those comparisons may then be used with sample data from known targets to classify the rest of the data in the image.

Such classification operations have two advantages over simple visual analyses. In the first place, each material has a characteristic pattern of reflectance which varies in a unique manner across the electro-magnetic spectrum. Secondly each gray-scale number on the tape represents the cumulative intensity of reflected solar energy from an object or group of objects across a given range of wavelengths (a spectral band). The variation in gray-scale values across the four MSS bands for a given pixel can be expected to summarize the characteristic patterns of reflected solar energy from objects in the pixel location, in the same manner in which summary statistics are used to describe mathematical distributions. It is logical to conclude that the possibility of identifying an object made of a given material or set of materials increases significantly each time information is added from another spectral band about the reflectance level of that object. This is particularly true if the bandwidths have been selected precisely to maximize the differences in reflectance patterns, as was the case with the ERTS satellite.

ERTS data in digital form can be preprocessed in any of a number of ways to make it more usable for a specific purpose and/or to enhance the visual appearance of the digital image. Figure 3 in the main text, for example, was produced by preprocessing the data used for Figure 2 to normalize it, eliminiatng the blocky appearance of the pixels. A *Sin x/x* function was used to break each pixel into 36 equal segments and create a gradual change from the value at the center of each pixel to its neighbors' central values. The result is much more pleasing to the eye; and some features (e.g., the 14th Street bridges) that are considerably narrower than a pixel become much more visible.

All of these features of ERTS digital data were used to determine whether or not Type IIID missile sites could be visually or digitally identified and located. In the [redacted] ICBM Complexes, 40.4- by 29.2-km (512- by 512-pixel) sample areas were selected to provide a large number of Type IIID missile sites for analysis. A total of 83 of these sites were then located on classified satellite photography.

25X1D

25X1D

In order to locate the same sites on the ERTS imagery, the investigator obtained 70-mm band 5 regular and gridded transparencies of the sample areas.* These images were placed alongside the classified satellite photography so that the sites could be located on the ERTS image by use of a defocusing technique in which both images were taken partially out of focus to get major feature alignment and then put back in focus to tally the exact pixel coordinates. This technique was successful enough that the concrete aprons of the missile sites were located in every instance and found to occupy four or fewer pixels. The aprons were chosen as the principal target because all of the other features of the missile sites were so small in relation to the size of a pixel that the variety of materials present on the rest of the site would have completely confounded efforts to find a uniform signature.

Next, computer listings of gray-scale values by pixel location were used in conjunction with the pixel coordinates to discover the gray-scale values for each pixel containing part of the concrete apron. The distributions of these gray-scale values were then plotted over the general distributions of gray-scale values for each band, so that a visual comparison of the data could be made (Foldout A-1).

A number of normalizing preprocessing techniques were used, but none of these seemed to make a significant difference in the distribution of the missile-site data. The *Sin x/x* convolution was attempted in both the *x* and *y* directions, and in the *x* direction alone for the [redacted] sites, but the distribution of data was so like that of the original data that these attempts were abandoned, and the results are not displayed here. Convolutions also did not appear to affect the visual resolution favorably.

25X1D

Simple visual analysis of the histograms in Foldout A-1 reveals that there is no situation in which ERTS data in any single band could be used to isolate the Type IIID sites; there is simply too wide a variation in the gray-scale values of the site pixels.

The most probable explanation for this variation is related to the difference in size between the concrete apron and the pixel. The 67- by 11-meter pad does not come close to filling a 79- by 79-meter pixel sampling area. Consequently, the relatively "bright" reflectance of the concrete in the pad must always be averaged with the reflectance totals of other materials in the pixel area (fences, trees, bare ground, etc.) to arrive at the gray-scale value for the entire pixel. This background material varies from site to site, as might be expected. Also, pixel boundaries seldom fall in the same location in relation to the sites, and the configuration and orientation of missile sites of the same type vary widely. Loading aprons which are located on three or four adjacent pixels are frequently represented by pixels in which only a very small portion of the gray-scale reading is attributable to the concrete in the apron.

Snow cover disrupts both the general and missile-site gray-scale distribution patterns by adding high reflectance values in all bands except band 7. Examination of the [redacted] sites on classified satellite photography revealed that the snow is cleaned from some of the concrete aprons and not from others; this problem almost surely added to the wide range of values observed.

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In band 5 the distribution of gray-scale values for missile sites is skewed to the right of the general distribution of values in each scene. To a lesser degree, the same phenomenon is noticeable in band 4. This was expected, since concrete has a relatively bright return on normal panchromatic photography. The skewing effect was an indication

*These images were obtained by processing ERTS tapes on CIA computers and displaying the digital data on an electron-beam recorder.

25X1D

that multi-band classification techniques might be used with some success to at least narrow the search for missile sites.

Multi-band analysis of the data was accomplished on the General Electric "Image 100," a high-speed mini-computer designed specifically for simultaneous analysis of data from the four MSS bands of ERTS digital tapes. It is an interactive system which allows visual as well as digital analysis.

The Image 100 was first given each four-band combination of gray-scale numbers that had been found in missile-site pixels to determine how many other pixels in that scene had exactly the same numerical signature. The computer analysis was accompanied by a visual display, in which the pixels having the same four values as the entry data were shown in a bright color, or "alarmed." The results of this first test can be seen in Table I and in Foldout A-2.

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The anomalous data for [redacted] were probably a result of the narrow gray-scale distributions in bands 6 and 7 (Foldout A-1), most likely caused by high absorption of solar radiation by the soil, which was saturated at the time the scene was recorded. The number of other pixels alarmed by any one four-band signature at the other three complexes ranged from none (meaning the missile-site pixel had a unique signature) to 309, with an average of 60.72 pixels for the three complexes. Although the relative position of these figures in the statistical distribution of all possible combinations of gray-scale numbers is unknown, fewer pixels than expected were alarmed in each 262,144-pixel sample area. In addition, the spatial distribution of alarmed data on the television screen appeared to be fairly random, even in the snow-covered [redacted] image. Three-band, two-band, and single-band analyses of this type, as expected, alarmed exponentially larger numbers of pixels, as the statistics below and in Figure A-1 show.

TABLE II

THE POWER OF MULTI-SPECTRAL CLASSIFICATION

Pixel No.	All Bands	Bands 4, 5 and 6	Bands 4 and 5	Band 5 Only
1	82	101	1338	8439
2	116	297	826	7303
3	310	604	2531	10700
4	2	21	1766	9141
5	104	333	1241	6123
6	44	481	3157	10706
7	~~11~~ 1	6	339	7822
8	16	40	224	5934
Total	~~685~~ 675	1973	11422	66174

A second type of test was performed by analyzing the distributions of missile-site gray-scale values and thereby determining maximum and minimum limiting values in each spectral band for identification of missile sites. In the [redacted] area, for example, limiting values of 25 through 34 were established in band 4, 20 through 29 in band 5, 42 through 51 in band 6, and 22 through 28 in band 7. The drastic increase in the number of possible numerical combinations that resulted from this procedure was immediately evident (Table III and Foldout A-2). 25X1D

Considering the large numbers of pixels alarmed by this method, it may be safely concluded that the use of a general classification scheme based on

TABLE I

RESULTS OF INDIVIDUAL MISSILE-SITE SIGNATURE EXPERIMENT

Complex	No. of Missile-Site Pixels	Total Pixels Alarmed	Average No. of Pixels Alarmed for Each Missile-Site Pixel	Range of Pixels Alarmed by Each Missile-Site Pixel Signature	Variance (σ^2) of Alarmed-Pixel Distribution	Standard Deviation (σ) of Alarmed-Pixel Distribution
[redacted]	51	3225	63.24	1–212	3358	57.9
[redacted]	41	1875	45.73	2–214	2303	48.0
[redacted]	42	29022	691.00	6–2713	817277	904.0
[redacted]	28	2049	73.18	1–310	4310	65.7

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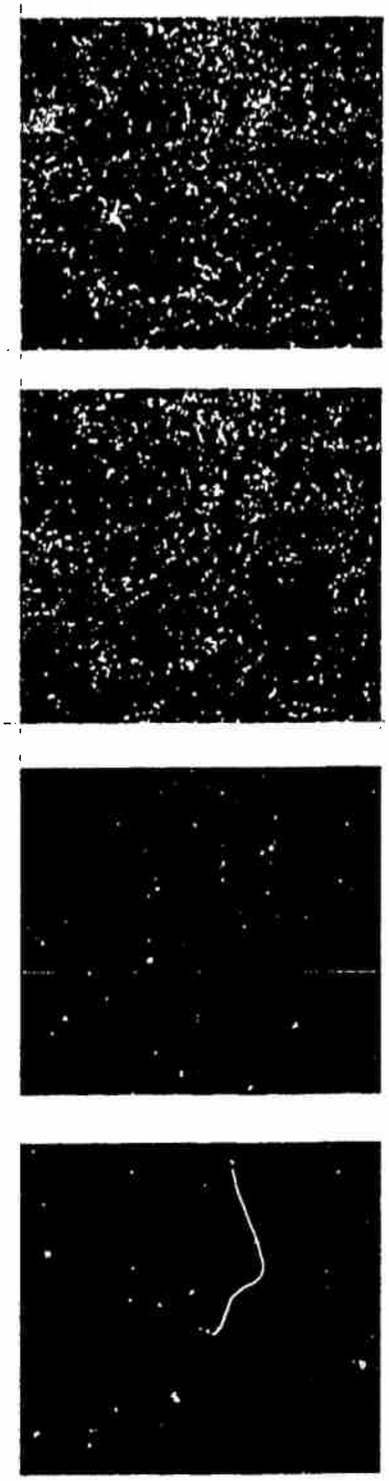

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Figure A-1. The effects of multi-spectral classification in significantly reducing the number of falsely "alarmed" pixels may be seen in this four-image sequence from the General Electric Image 100. In the first image, band 5 values from eight missile-site pixels in the [redacted] sample area were used as inputs, and all other pixels with the same value were alarmed. In the second, bands 4 and 5 values from the same eight missile site pixels were used as the limiting combinations; and in the third, bands 4, 5, and 6 constraints were added. The fourth image, which uses the data from all four spectral bands, represents a different set of eight missile-site pixels from the same image but is included in the sequence for visual impression. The effect is immediately apparent: adding data on any signature from new spectral bands drastically reduces the amount of possible classification errors. The statistical data to accompany these scenes appear in Table II.

Photographs courtesy of General Electric

Approved For Release 1999/09/26 : CIA-RDP86T00608R000600140007-5

TABLE III

RESULTS OF CLASSIFICATION INTERVAL EXPERIMENT

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Area	No. of Missile Site Pixels	Total Pixels Alarmed	Percent of Frame Alarmed
[redacted]	51	54,923	20.95
	42	38,340	14.63
	41	67,194	25.63
	20	34,380	13.12

ranges of values in each spectral band simply will not succeed for identification of the Type IIID missile sites. Use of individual site signatures (Table I) for all four bands restricts the number of possible combinations and markedly reduces the number of pixels alarmed; but since there were only six instances (four of them in the [redacted] image) of missile-site pixels having identical combinations of gray-scale values, the latter technique for locating the Soviet missile sites is also virtually precluded.

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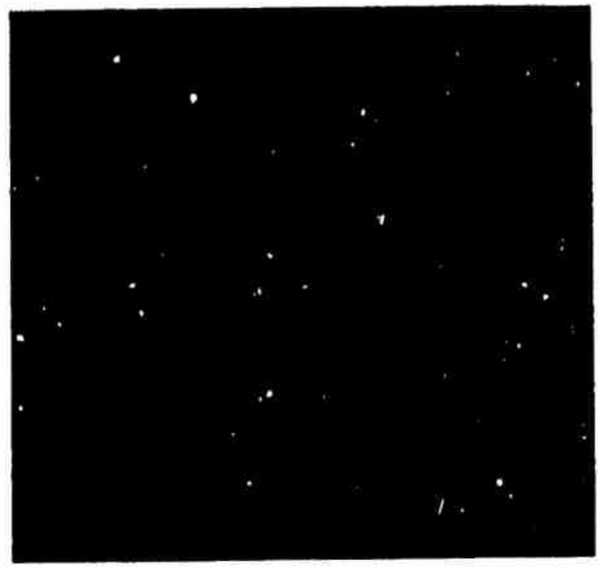
These results do not imply, however, that the method is unsound or that the MSS data of some future earth resources satellite could not be used for such a purpose. If the pixel size were reduced to 28 by 39 meters, for example, the concrete apron would occupy a much larger part of a pixel on the average, and the solar reflectance signature of the apron would contribute much more heavily to the gray-scale value of the pixel. Some of the relatively small features, such as the steel silo door rails, would also provide a greater input to the total cumulative radiation sensed in each pixel, but the latter phenomenon would be far less significant than the increased contribution of the concrete area to the pixel radiation signature. The range of values encountered for missile sites (Foldout A-1) would almost certainly narrow, increasing the probabilities of obtaining the same gray-scale values for separate missile sites.

The investigators also used ratio techniques with the Image 100 to discover whether these techniques would visually eliminate some of the non-missile sites. These techniques—successful in identifying certain kinds of geological structures, minerals, and soil types—consist of dividing the gray-scale value of a pixel in one band of an image by the corresponding value for the same pixel in another band, and then giving the new distribution of values a gray-scale range and showing it on the screen as a digital image. A wide variety of ratio combinations were examined in this manner.

The images of the ratios of band 4 to band 5 and band 5 to band 7 appeared to have the most value in this respect (Figures A-2 and A-3). On the first image the drainage pattern is clearly apparent, and any alarmed pixels in the ravines could be eliminated visually as potential missile sites. The image of the band 5/band 7 ratios can be similarly used to eliminate pixels falling in poorly drained, swampy areas, which appear in dark tones. In both of these cases such information was not evident in the original images, where many of the ravines and swamps were obscured by forest cover, snow, and other features.



25X1D

Figure A-2. This image of the [redacted] sample area was obtained by dividing the value of each pixel in band 4 by the corresponding value in band 5, establishing a new gray-scale for those values, and showing the resultant image on the screen of the Image 100. The mountains, which are in fact quite heavily forested, appear denuded, and the drainage pattern appears in strong relief.

25X1D

Figure A-3. The [redacted] area was similarly examined. The image of the ratio of band 5 to band 7, however, reveals entirely different features. On this image, the poorly drained areas stand out in dark tones. (Contrast this scene with the corresponding color-infrared composite in Foldout A-2.) Any alarmed pixels within these swampy areas would almost certainly *not* be missile sites because of the problems of constructing watertight underground installations.

APPENDIX B

Acquisition of ERTS Data by the PRC

Representatives of the Peoples Republic of China have openly expressed an interest in using ERTS imagery for domestic studies and have requested information on ERTS through European map dealers. Recently a U.S. scientific exchange delegation presented a complete set of available ERTS images (about 400) covering mainland China as a gift to the Institute of Geophysics in Peking. Representatives of the PRC have also approached U.S. firms to explore the purchase of ERTS ground receiving station equipment. Whether the Chinese interest extends to using ERTS for strategic and economic analysis of foreign territories is not known, but seems likely on the basis of the analysis presented in preceding sections. It is worth noting in this regard that the intelligence service of the Republic of China, on Taiwan, has used a subsidiary organization to order selected ERTS images of strategic military targets within mainland China.

If the PRC has obtained ERTS imagery over foreign areas, the purchase has probably been made through a second party willing to protect the purchaser's identity. Two sets of ERTS orders that appear to fit this pattern are examined here. Both requested ERTS data over territories adjoining China and were placed by a Danish book dealer who has a history of obtaining U.S. data for Communist countries.

The first order was placed in a series of letters written to the Sioux Falls Data Center between September 1972 and October 1973. An earlier study of this order reviewed the correspondence up to June 1973 and concluded that it had probably originated with the PRC.* That conclusion was based on the dealer's previous associations and on the fact that the request specified complete coverage of China and neighboring countries to a distance of about 1,500 kilometers from the Chinese border (see map, following page 22).

*Probable Chinese Collection of US Satellite Imagery, CIA/BGI RP 74-1, August 1973, S/NFD.

Exchanges of letters since the date of the earlier study reveal that the basic order from the list of images available at that time has now been filled and identify the specific images and types of ERTS products that were shipped. The most revealing information was contained in a letter from the Dane on behalf of his "client," in October 1973. It identified 387 ERTS scenes that met his selection criteria.

The area over which the images were actually ordered is radically curtailed from the purchaser's original request. It comprises only the western and southwestern parts of the total area of expressed interest, including parts of India, Afghanistan, Pakistan, western China, and Soviet Central Asia (Map 1). Perhaps significantly, it excludes coverage of some of the most sensitive installations in that part of the USSR. This selection of imagery does not cover the area expected to be of the highest military and economic interest to the PRC, the Soviet border zone farther to the east. The area included in the final order would appear to be of greater interest to the USSR, or perhaps to India. The fact that the order was placed through a cut-out rather than directly—as is the normal practice observed for both the USSR and India in ordering limited coverage of their own territories—indicates a sensitivity about the intelligence-gathering implications of the order.

For 99 of the scenes covering areas within and near the USSR, the Dane's client ordered 9- by 9-inch images of each of the the four MSS bands on "N3 negative Kodak duplicating film 2422" (396 copies, costing $1,188). This product is most suitable for producing contact prints in large quantities. Choice of the 9- by 9-inch format (1:1,000,000 scale) would be convenient for reproduction and further enlargement using standard photogrammetric facilities.

The second part of the order, for 288 scenes, requested 9- by 9-inch images in each of the four

MSS bands on "N4 negative Kodak 2430 film" (1,152 copies, costing $6,912). This product is obtained by converting the N3 negative into a positive image, and then reconverting the latter to a negative. This process results in some resolution degradation but provides better density range in the film for producing color composites or for radiometric analysis. This type of film also has advantages for producing mosaics and photomaps. As a courtesy the purchaser is also given the N3 negatives from which the order was processed.

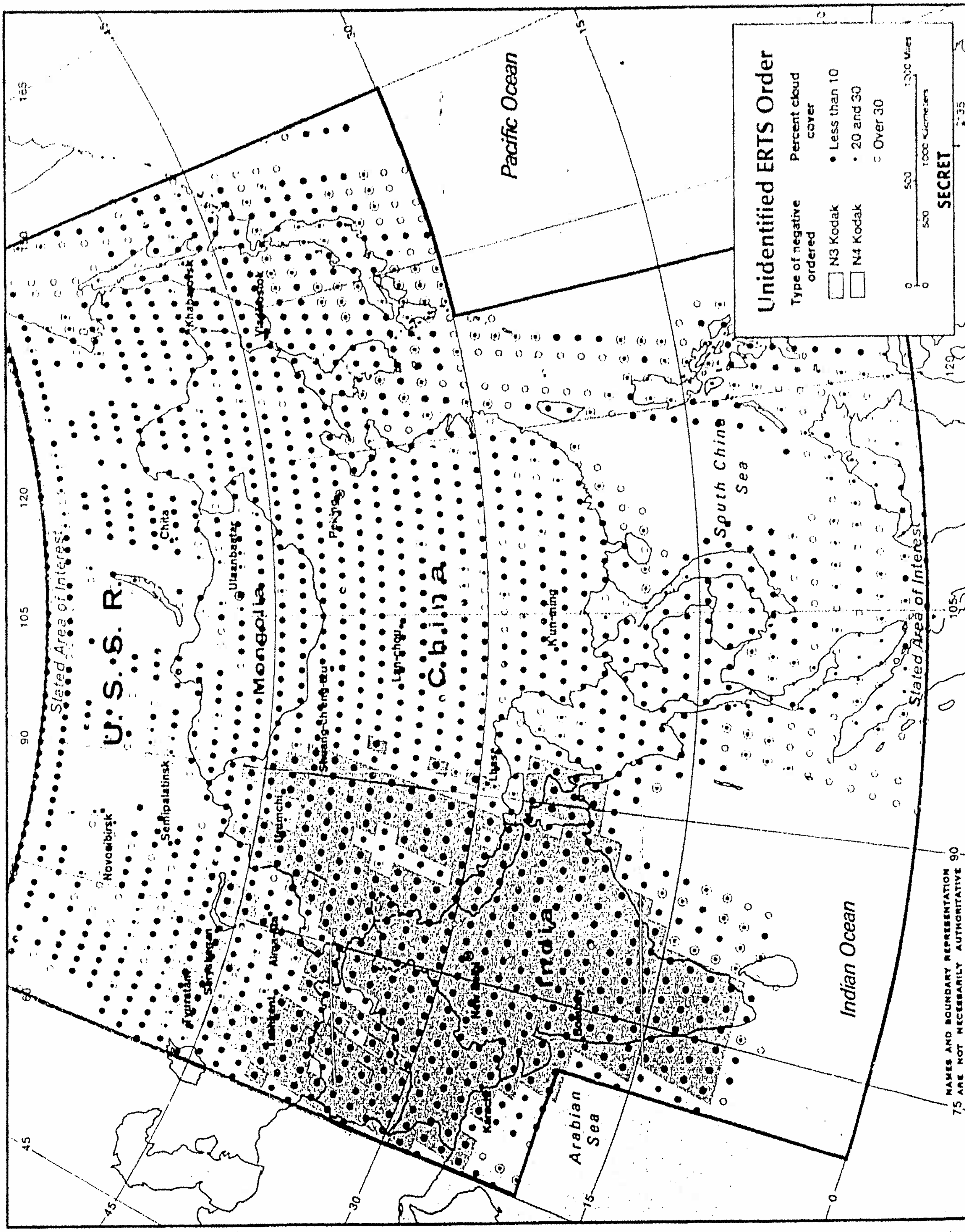
Additional orders for this client are expected from the Danish book dealer as new ERTS coverage is acquired. He has specifically requested periodic computer printouts of all new coverage over the entire area shown on Map 1 and has lowered his selection criterion to 30 percent cloud cover in any scene rather than only 10 percent.

An entirely new order from the Danish book dealer, which may be for a different client, in December 1973 requested sample copies of color composites covering the Siberian area between 117°E and 138°E. The letter did not specify the northern or southern boundaries of his area of interest, but it includes at least the entire USSR-PRC border east of Mongolia.

Based simply on the known associations of the book dealer and the area covered, it seems likely that the second order is either a Soviet attempt to acquire data for resource studies or a PRC attempt to obtain strategic information about the USSR. Japanese and other international firms have commercial, economic, and exploration interests in East Siberia and the Soviet Far East, but such firms routinely order ERTS data themselves. Nevertheless, it is possible that even a commercial firm might seek to disguise its interest in an especially sensitive area.

These two orders for ERTS data are examples of how the PRC could obtain imagery over neighboring countries with a minimum chance of detection. Of the many hundreds of other foreign orders for ERTS data that we have examined briefly in an attempt to identify the purchaser, none has been detected as being of definite PRC origin, although in many cases the intended disposition or use of the imagery cannot of course be determined.

SECRET



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APPENDIX C

Geodetic and Cartographic Factors for Missile Targeting

The geometric quality of ERTS imagery is adequate for significant, although limited, cartographic and geodetic uses. ERTS materials can provide the geographic coordinates of photo-identifiable targets in denied areas. This application may be attractive to nations which possess surface-to-surface missiles but lack their own satellite reconnaissance systems. ERTS imagery could also be used in the construction of general-purpose photomaps or navigation and air-target charts covering areas for which other maps are not available.*

The prime consideration in mapping is the amount of image distortion produced by an imaging system. Images from the RBV and MSS systems contain external as well as internal errors. External errors—originating mainly from uncertainties about spacecraft alignment, ephemeris, and attitude—are common to both systems. Internal errors are different for the RBV and MSS systems. The RBV internal distortions, which are caused by optical and electromagnetic errors in the camera, are by far the larger. The main MSS internal distortion consists of pixel displacements at regular intervals or omitted or displaced image lines.

Because each RBV image is obtained at a specific point in space it can be systematically corrected for measurable distortions. Internal and external errors cannot be separated in MSS images; corrections are made by measuring points on an image and identifying and isolating specific errors. With both imagery types, careful processing can eliminate most of the image distortion.

*Research on the geometric properties of ERTS imagery has been too limited to provide a final assessment of that system's capabilities. Furthermore, the discussion that follows is based on work that has been accomplished by USGS using ERTS-1 data; LANDSAT-2 imagery processing will be modified to add Overlap Reference Marks in the image margins that are common to successive frames, thereby improving extension of geodetic control along the orbit path. Recent research suggests that additional significant improvements may be possible, and may eventually allow *independent* mapping from LANDSAT imagery with positional accuracies significantly better than the present 2,000 to 5,000 meters.

Geodetic Accuracies

The capability for geodetically positioning photo-identifiable points from ERTS images varies widely, depending on the image products used and on the availability of supplementary data over the area covered by the ERTS imagery.

The least favorable situation arises when the user possesses only ERTS bulk imagery and no other cartographic or geodetic data over an area to which he does not have access. The only positional information is provided on the image itself, which carries the latitude and longitude coordinates for the mid-point and edges of the scene. For both RBV and MSS bulk imagery these coordinates may be in error by 2,000 to 5,000 meters from the local coordinate system.

A second case occurs if the user has obtained precision image products from the distribution center.* In precision processing, positional errors on the image were determined by comparison with known locational data for a number of ground points. Image distortions were then corrected and location tick marks are applied to the printed copy. This procedure resulted in a noticeable degradation of image resolution quality and was only possible for areas where NASA has available geodetic data or adequate maps. Identifiable points on precision processed imagery were located with a root-mean-square (*rms*) error of about 100 meters for RBV products and 150 to 200 meters for MSS products (Figure C-1).

*Precision products are no longer produced by NASA.

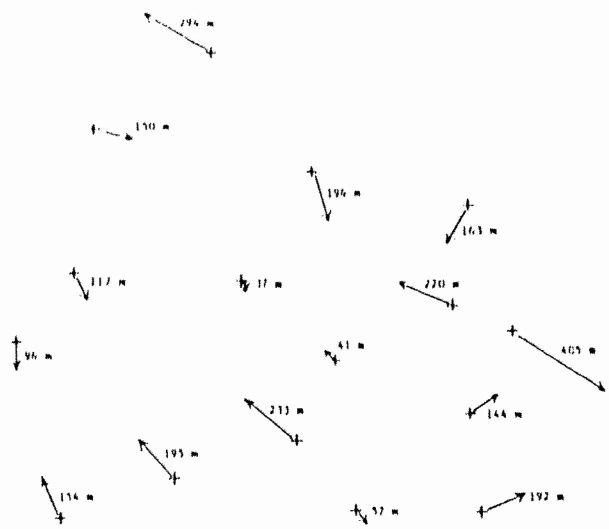


Figure C-1. Distortion pattern in an MSS image of Chesapeake Bay. Average position error in this image is about 200 meters.

A third set of circumstances appears when the user possesses photo-identifiable ground geodetic data or large-scale maps within the area covered by the ERTS image. Photo-identifiable ground control in an ERTS image can be measured to an accuracy of 15 to 25 meters on RBV and 25 to 50 meters on MSS imagery.* If two or three known control points are in the image, the residual *rms* error in location of points in the rest of the image amounts to about 200 meters. Knowing 10 to 15 control points allows identification of systematic distortion patterns and reduces the residual *rms* error to 50 to 100 meters.

The errors described for the above case could be considerably larger if, instead of having ground control or equivalent large-scale maps, the user is limited to inferior maps covering the area of interest. In this situation internal map errors contribute a significant amount of uncertainty to the overall control of the ERTS image. Looking at this specifically from the point of view of the People's Republic of China (PRC), the map acquisition problem varies in difficulty by region. Against the United States, it is known that the PRC has successfully used third-country map dealers to obtain extensive coverage at large scales. Coverage of Western Europe is even more readily available and has presumably been obtained to the extent desired.

Maps of the USSR are a high priority collection requirement for the PRC and have been sought for many years through a host of sources.* Medium- and large-scale Soviet-produced maps of the USSR are classified and probably have not been obtained by the PRC in quantity. There is some evidence, however, that for part of the western USSR the PRC has been successful in obtaining 1:100,000 maps that were captured by the Germans during their invasion of the USSR in World War II. The best unclassified Soviet maps available to the PRC are the 1:500,000- and smaller-scale administrative series and the 1:2,500,000 hypsometric series, which are 10 and 15 years old, respectively. Unclassified maps published by the USSR since the mid-1960's have been deliberately distorted by the introduction of locational errors of up to 40 kilometers.

For most of the USSR, the best maps that the PRC has been able to obtain are probably those that have been produced by the United States. Joint Operations Graphics (JOGs), at 1:250,000, have been published for most of the USSR. Although they are not normally available to the public, they are unclassified and are known to have been sought by the PRC; the degree to which they have succeeded in this effort is unknown. Availability of JOGs would allow transfer of positions of photo-identifiable ground points from the map to the ERTS imagery with an *rms* error range of 200 to more than 400 meters in horizontal position. U.S.-

*Photo-identifiable points, in this sense, refer to intersections of roads or other linear features that can be located on the image by extrapolation of the visible lines through a number of pixels. Determination of the locations of point features, such as missile silos, may be possible only to the nearest several pixels and may also be affected by unknown microdistortions, particularly random displacement of pixels.

*"Communist Chinese Attempts to Obtain Maps and Related Information," OSI-SID-71-2, February 197?, S/NFD.

produced Tactical Pilotage Charts (TPCs), at 1:500,000, and Operational Navigation Charts (ONCs), at 1:1,000,000, covering at least a part of the USSR, are known to have been purchased by the PRC. The *rms* horizontal error of position for points in the USSR ranges from 350 to more than 700 meters for the TPCs and 700 meters to more than 1,400 meters for the ONCs.

A fourth case for geodetic positioning from ERTS is found when the user possesses geodetic or map control at two locations and ERTS imagery covering the controlled points and the entire strip between them. This situation might occur along the USSR-PRC border: the PRC has good control on its side and may know the precise location of certain sites in the USSR such as the astronomical observatories at Irkutsk, Tomsk, and Alma Ata. This photogrammetric technique, called *bridging*, allows interpolation of the known control through intermediate images from the same orbit along great distances. A USGS experiment over a distance of about 2,000 kilometers in the United States, in which eight control points were available in the first image and four in the last, resulted in an average *rms* error of 483 meters for all test points in intermediate images. Errors would be less over shorter distances. A variation on this technique, bridging across ERTS imagery from different satellite orbits, would be expected to yield somewhat larger errors along equivalent distances.

A similar photogrammetric technique, called *cantilevering*, can be applied when geodetic control is known at only one end of a strip of photography. In this case the errors within the first ERTS image beyond the controlled area might reach 200 to 300 meters. Errors in more distant images would presumably occur as multiples of the first. Along a border where one country has good control on its side, it has the capability of positioning photo-identifiable points to a distance of 80 kilometers on the other side with an accuracy of about 100 meters. (See third example above.) Using the cantilevering technique in the next image beyond the border, the area between 80 and 250 kilometers beyond the border can then be positioned to an estimated accuracy of 200 to 300 meters.

Potential Contribution to PRC Missile Accuracy

The average miss-distance or circular error probable (CEP) of PRC ballistic missiles is estimated to be about 2 kilometers for the medium range missile and 2 to 4 kilometers for the intercontinental version. Of the total targeting error, a major part—deriving from guidance system and reentry vehicle design—is largely unaffected by choice of target; flight distance is the critical factor. The geodetic and gravitational (G&G) contribution to the total CEP, on the other hand, is critically dependent on data that are not equally available for all locations.

G&G error consists of three subcategories—launch area, gravity model, and target position. The first two are beyond the scope of this paper. The third, determination of the target position on a local geodetic system, could be very difficult for the PRC in some areas and could be significantly assisted by use of ERTS data.

According to recent estimates, the PRC is technically capable of achieving G&G accuracies to targets in the United States and South and East Asia that generally meet their requirements.* High quality U.S. maps are freely available and target position uncertainties are only a minor part of G&G error. Against targets in East Asia and South Asia the total G&G error is as much as 1,000 meters in some areas because of the differences in quality of some available local maps. ERTS data over these areas could be used to update the existing maps and to bridge gaps in map coverage.

ERTS imagery could be used to the greatest advantage by the PRC for targeting in the USSR. Earlier it was noted that unclassified Soviet-produced maps have little utility for positioning USSR targets. Large-scale Soviet topographic maps and U.S. JOGs, if they have been acquired at all, are probably available for only a part of Soviet territory. For its basic coverage of the USSR, the PRC probably is forced to rely upon U.S.-produced

*A more complete treatment of this topic is contained in *Communist Chinese Geodesy as Related to Missile Accuracy*, CIA OSI-STIR/70-10, April 1970, S/NFD; and *USSR/PRC ICBM Geodetic and Gravitational Capabilities*, ACIC Technical Report No. 102, February 1971, S/NFD. The 1970 study by OSI is presently being revised.

TPCs and/or ONCs at 1:500,000 and 1:1,000,000, respectively.

The ONCs and TPCs provide adequate position data to target missiles against major urban centers, where the target itself is several thousand meters in extent.* They also identify major airfields and transportation systems, although the average positional errors of 350 to more than 1,400 meters would probably create an unacceptable bulge in the total missile error budget.** ERTS imagery can be used to revise and update these maps or to verify their accuracy. The maps in turn provide a locational framework for the ERTS images.

*The operational CSS-3 missiles, which could be used against the USSR, are estimated to carry a 3-megaton warhead, which would produce substantial urban area damage over a radius of 5,000 meters and destroy certain hard targets more than 1,000 meters from the impact point.

**This discussion refers only to horizontal positions. Vertical (elevation) data is also critical to missile targeting, but useful elevation measurements cannot be produced from ERTS imagery.

Within a few hundred miles of the China-USSR border, and farther into the USSR if the PRC possesses geodetic control on Soviet locations that permit use of bridging techniques, ERTS imagery could considerably improve positional information over what is available on TPCs and ONCs. This is noteworthy because a large part of the Soviet ground, air, and missile forces deployed against the PRC are located within 150 kilometers of the border.

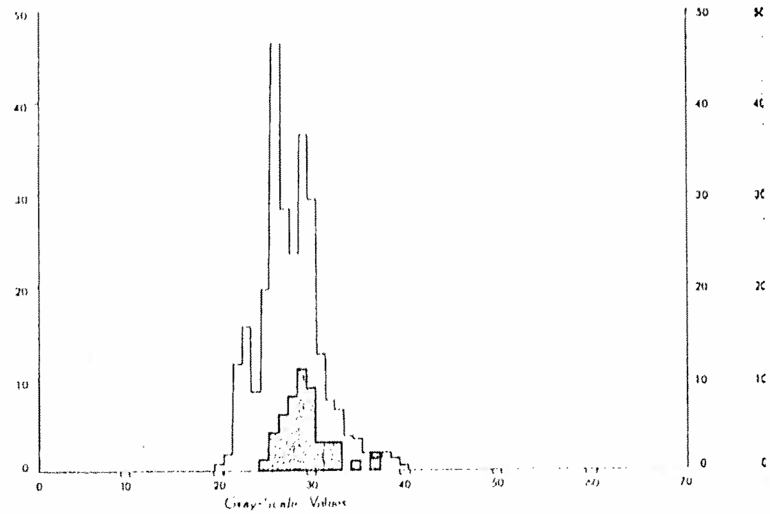
As noted in the main text, the resolution of the ERTS imagery allows identification of many of these large ground-forces concentrations and airfields, and collateral can assist with identification of some missile installations. Use of photogrammetric cantilevering techniques would permit positioning photo-identifiable points within these nearby sites to an accuracy of 50 to 300 meters, which is equivalent to PRC capabilities against other neighboring countries.

BAND 4

25X1D

[redacted]

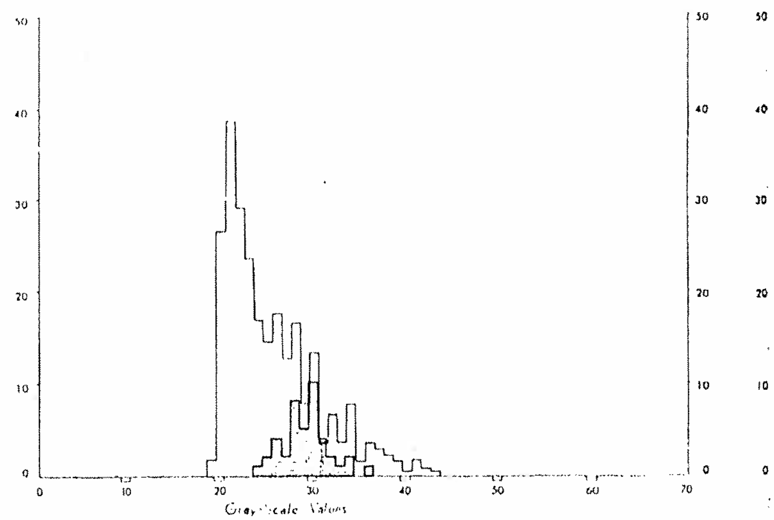
The distributions of gray-scale values of the sample area in the visible portion of the spectrum (bands 4 and 5) are bimodal; the peak in the lower range of values represents the forest cover, which reflects relatively little radiation; and the second peak probably is attributable to the agricultural fields, though the normal range of response is much wider for that category. Missile sites, like urban features in general, tend to have relatively high reflectance levels—a fact which accounts for the skewed distribution for band 5. The range of values found in each band for missile sites is too great to permit the use of data in any one of these bands for identification.



25X1D

[redacted]

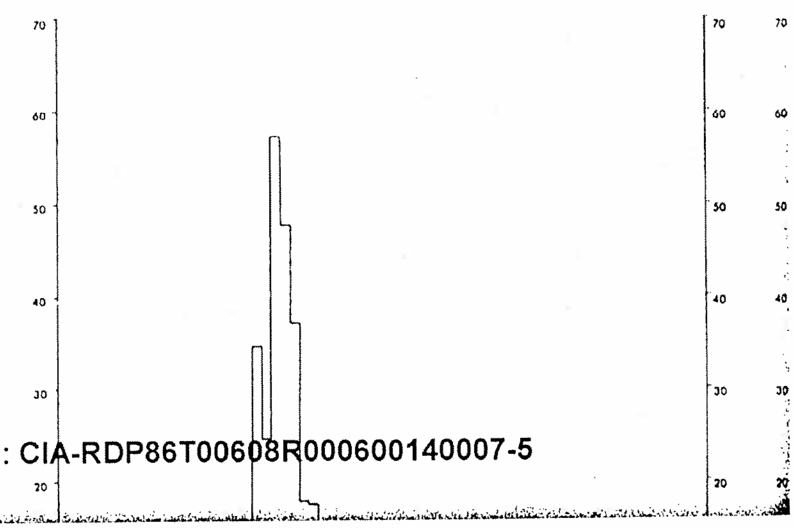
The high percentage of forest cover in this scene (see Foldout A-2) is reflected in the intense peak of values at the lower end of the distribution. In this case, as in the above example, the missile-site gray-scale values peak farther to the right than those in the overall scene. The distributions of values of both in the infrared portion of the spectrum, however, are almost identical, signifying that there is little hope of employing the infrared bands by themselves for automated identification.



25X1D

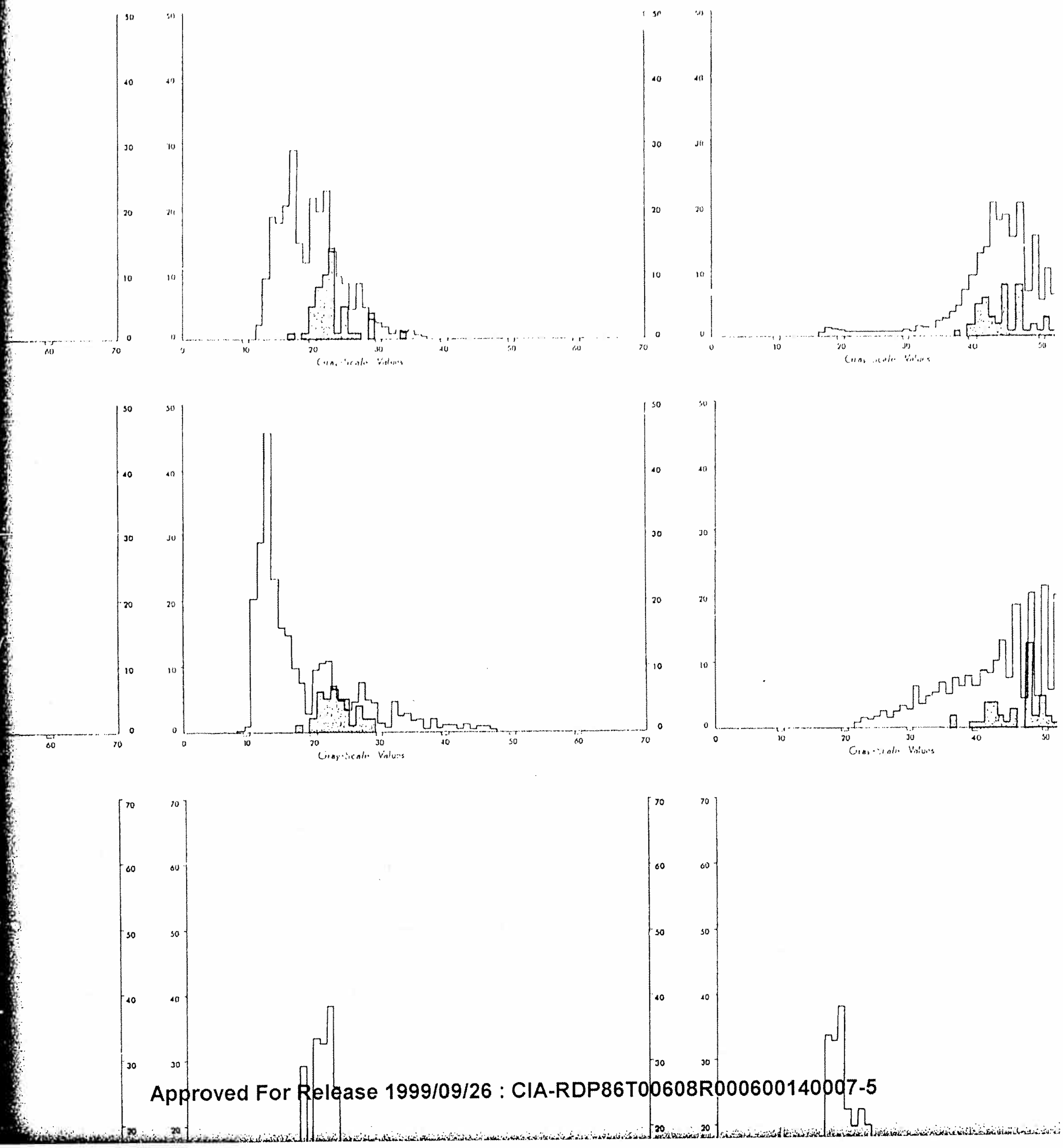
[redacted] 25X1D

The area around [redacted] is almost exclusively agricultural. The image was exceptionally difficult to interpret because it was recorded in late March, when the soil had just thawed and was extremely saturated and there was little or no green vegetation. The high rate of absorption of incoming radiation by the saturated soil is probably responsible for the high, narrow curve of values at the low end of the gray-scale range in band 7. This factor essentially negated the usefulness of band 7 data as classification algorithms and resulted in the considerably higher number of pixels alarmed by both individual and classification-interval site signatures.



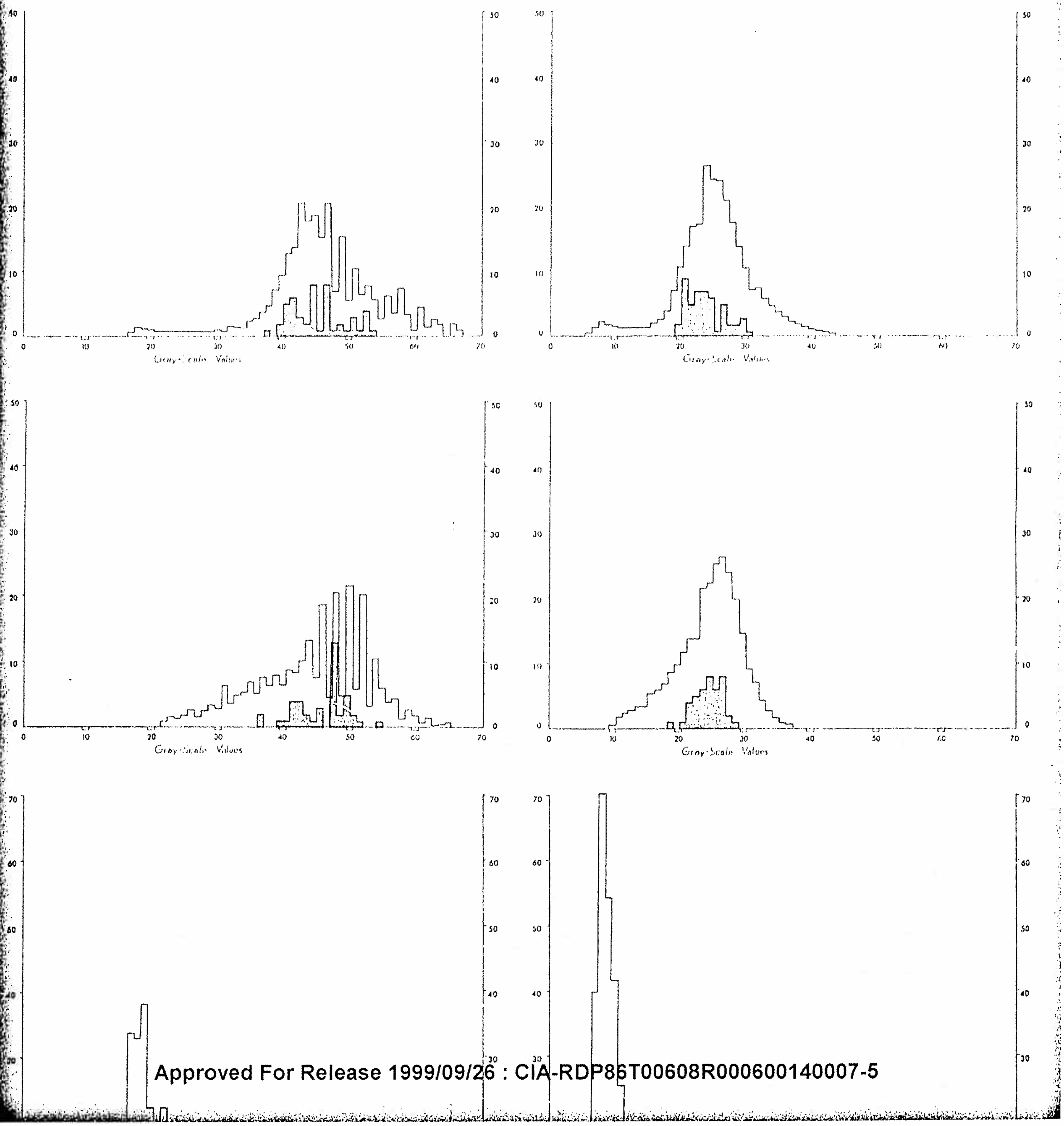
FOLDOUT A-1: THE SPECTRAL DISTRIBUTIONS OF ERTS-1 SAMPLE AREA AND MISSILE SITE DATA

BAND 5 BAND 6



CTRAL DISTRIBUTIONS
1 SAMPLE AREA AND
SITE DATA

BAND 6 BAND 7



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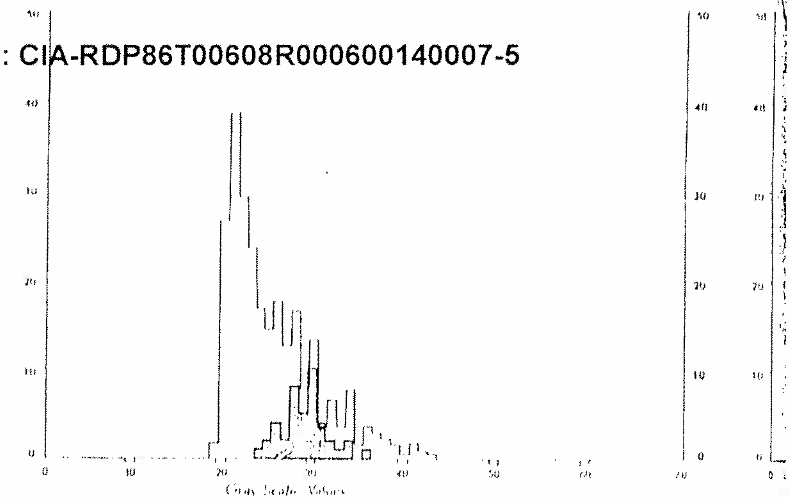
25X1D

[redacted]

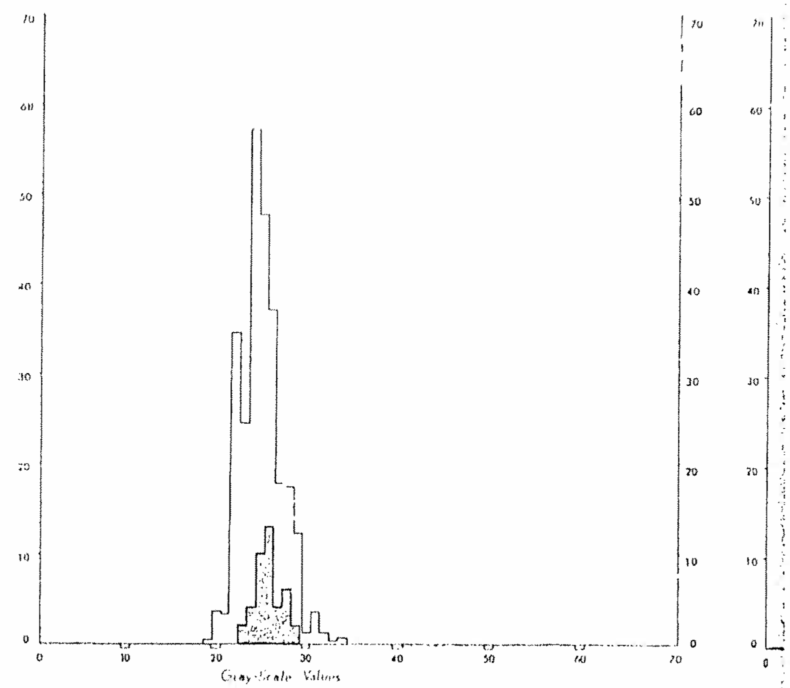
The hig[illegible] (see Foldout A-2) is reflected in the intense peak of values at the lower end of the distribution. In this case, as in the above example, the missile-site gray-scale values peak farther to the right than those in the overall scene. The distributions of values of both in the infrared portion of the spectrum, however, are almost identical, signifying that there is little hope of employing the infrared bands by themselves for automated identification.



25X1D

[redacted] 25X1D

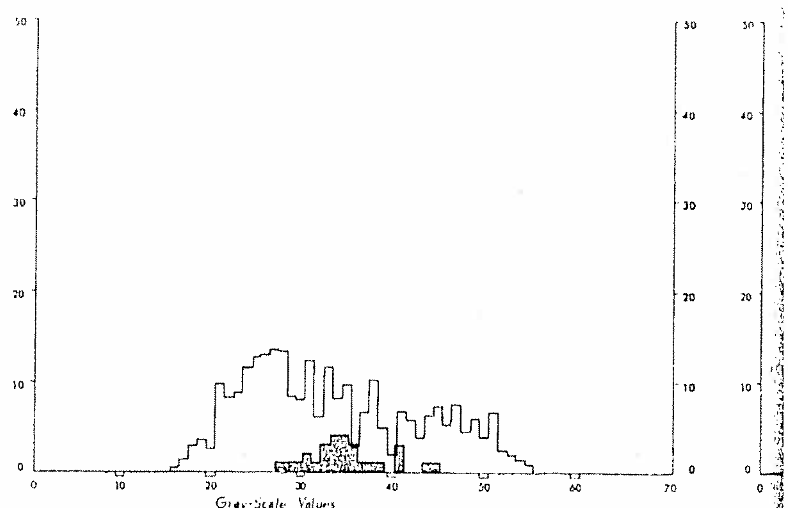
The area around [redacted] is almost exclusively agricultural. The image was exceptionally difficult to interpret because it was recorded in late March, when the soil had just thawed and was extremely saturated and there was little or no green vegetation. The high rate of absorption of incoming radiation by the saturated soil is probably responsible for the high, narrow curve of values at the low end of the gray-scale range in band 7. This factor essentially negated the usefulness of band 7 data as classification algorithms and resulted in the considerably higher number of pixels alarmed by both individual and classification-interval site signatures.



25X1D

[redacted] 25X1D

The hilly [redacted] area was snow-covered when ERTS-1 recorded this scene. The high absorption rate of the evergreens and high reflectance of the snow resulted in an extremely dispersed pattern of values in all bands except band 7, and the curve in that band was at the low end of the scale for the same reasons. Some missile sites were covered with snow and others had been cleared—a situation which certainly contributed to the broad range of values for the sites.



— OVERALL SPECTRAL RESPONSE (In Thousands of PIXELS)
— MISSILE-SITE SPECTRAL RESPONSE (Number of PIXELS)

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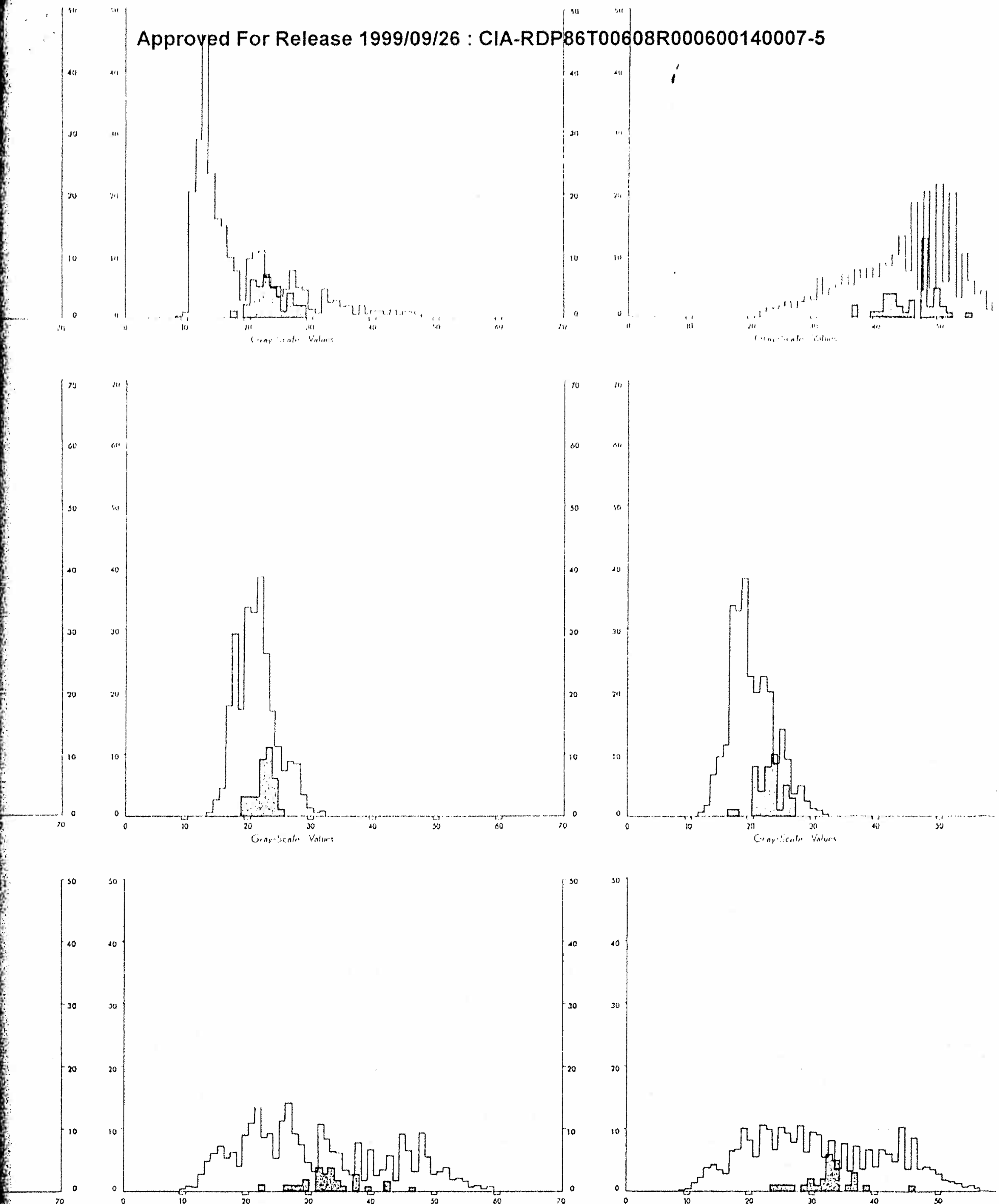
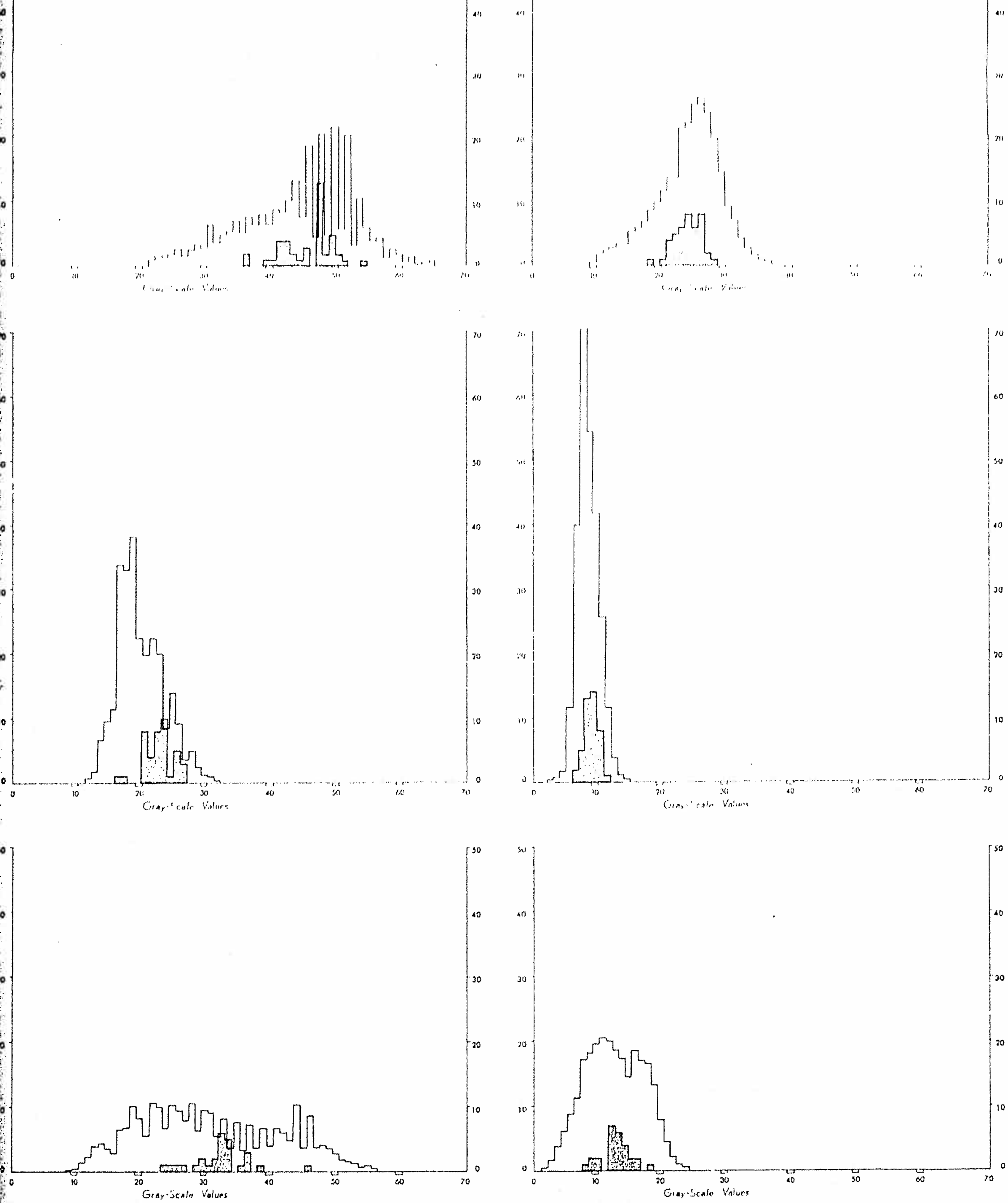
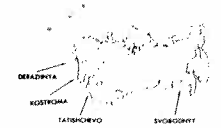


Approved For Release 1999/09/26 : CIA-RDP86T00608R000600140007-5


Gray-Scale Values
Gray-Scale Values

FOLDOUT A-2: CLASSIFICATION PATTERNS FROM SOVIET MISSILE-SITE DATA



25X1D

[redacted]

The sample area is 80 percent agricultural and 12 percent forested. The individual missile-site signatures alarmed an essentially random pattern, averaging 62 incorrect identifications for each missile site found. The use of general classification intervals in each band (based on the distributions in Foldout A-1) permitted a much greater number of mathematical combinations and alarmed 11 percent of the pixels (yellow shades) in the scene, mostly those representing field edges and light new vegetation.

25X1D

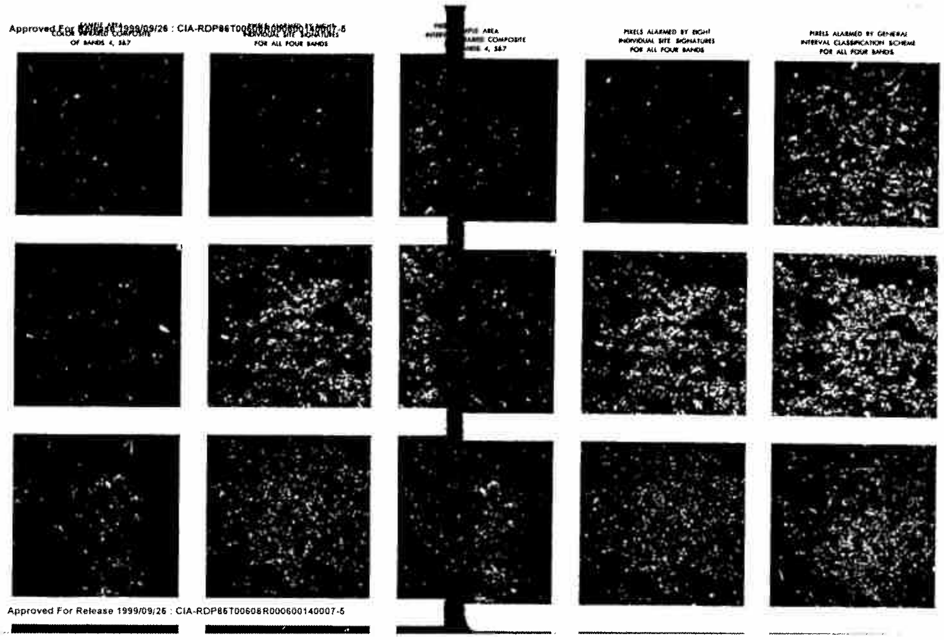
[redacted]

25X1D [redacted] area is 40 percent forest and 15 percent swamp with a relatively small amount, 20 percent, of its land devoted to agriculture. The missile-site signatures here alarmed, in a random pattern, an average of 45 pixels that did not represent missile sites. The classification intervals alarmed 13 percent of the 262,144 pixels in the sample area; in this case the erroneous alarms appeared to be restricted to random parts of the agricultural areas.

25X1D

[redacted]

25X1D This [redacted] has a strongly agricultural (80 percent) land-use pattern, with a relatively sparse 10 percent in forest. The large numbers of erroneous pixels alarmed by both individual signatures (an average of 690) and the classification intervals (26 percent of the scene) are almost certainly attributable to the anomalous data distribution in band 7 (Foldout A-1)



light new vegetation.

25X1D

[redacted]

[redacted] area is 40 percent forest and 15 percent swamp with a relatively small amount, 20 percent, of its land devoted to agriculture. The missile-site signatures have alarmed, in a random pattern, an average of 45 pixels that did not represent missile sites. The classification intervals alarmed 15 percent of the 262,144 pixels in the sample area; in this area the erroneous alarms appeared to be restricted to random parts of the agricultural areas.

25X1D

[redacted]

[redacted] has a strongly agricultural (80 percent) land-use pattern, with a relatively sparse 10 percent in forest. The large numbers of erroneous pixels alarmed by both individual signatures (an average of 690) and the classification intervals (26 percent of the scene) are almost certainly attributable to the anomalous data distribution in band 7 (Foldout A-1).

25X1D

[redacted]

[redacted] sample area is located in a hilly region, a [redacted] its 60 percent forest cover and sparse agricultural use (25 percent). Despite the fact that the region was snow-covered at the time the scene was recorded, the number of pixels erroneously alarmed by the individual site signatures was low (72) and the classification-interval experiment alarmed only 12 percent of the pixels in the frame.