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GEOLOGIC APPLICATIONS OF THERMAL-INERTIA MAPPING FROM SATELLITE

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Final Report - HCMM Investigation S-40256-B

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16. Abstract

This study is an evaluation of HCMM (Heat Capacity Mapping Mission) satellite data to detect and map geologic features for energy-resource and mineral-deposit investigations. In the Powder River Basin, Wyo., narrow geologic units having thermal inertias which contrast with their surroundings can be discriminated in optimal images. A few subtle but mappable thermal-inertia anomalies coincide with areas of helium leakage believed to be associated with deep oil and gas concentrations. Similar changes were not found in areas of uranium deposits possibly due to their minor and discontinuous nature at satellite resolution.

The most important results involved delineation of tectonic framework elements some of which were not previously recognized. Thermal and thermal-inertia images also permit mapping of geomorphic textural domains. A thermal lineament not on existing geologic maps or detected on Landsat images appears to reveal a basement discontinuity which involves the famous Homestake Mine in the Black Hill, a zone of Tertiary igneous activity and facies control in oil-producing horizons.

Applications of these data to the Cabeza Prieta, Ariz., area illustrate their potential for igneous rock-type discrimination. Extension to Yellowstone National Park resulted in the detection of additional structural information but surface hydrothermal features could not be distinguished with any confidence.

Advances in modeling and image analysis included the development of a new thermal-inertia mapping algorithm, a fast and accurate image-registration technique, and an efficient topographic-slope and elevation-correction method.

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1.0 PREFACE

1.1 OBJECTIVES

The principal objective of this study was to investigate applications of HCMM (Heat Capacity Mapping Mission) satellite data in detecting and mapping geologic features for energy-resource and mineral-deposit studies. Other, related objectives involved the development of new techniques and approaches in thermal modeling and image processing.

1.2 SCOPE

The analysis was somewhat restricted by the limited number of sequential day/night image pairs free of major atmospheric/weather problems. For the Powder River Basin, Wyo. area, a single thermal-inertia image was formed using 20 August 1978 data. Four additional nighttime scenes were used to examine geologic formation boundaries and thermal lineaments. The analysis of the Cabeza Prieta, Ariz., area was done using a thermal-inertia image constructed from data acquired April 3 and 4, 1979. No successful U-2 aircraf data acquisition flights were conducted over these two sites so that comparison of different resolution thermal data was only conducted using USGS aircraft data. Despite all these limitations, significant geologic information was derived in this study, and the results suggest the importance of a follow-on thermal satellite experiment for improved mineral and energy resource exploration.

1.3 CONCLUSIONS

Despite limited data, investigations in the Powder River Basin area of eastern Wyoming and adjacent States clearly showed that geologic units as narrow as two or three resolution elements, but of moderate to high thermal-inertia contrast against surroundings, can be discriminated in optimal images. It appears likely that subtle facies differences in sedimentary basin-fill units can be delineated and mapped using satellite thermal-inertia images, especially if sequential images can be obtained during a drying cycle after rain or snow. A few subtle but mappable thermal-inertia anomalies coincide with areas of anomalous helium in soil gas believed to indicate leakage from deep oil and gas concentrations; the presence of thermal-inertia anomalies suggests that gas leakage has produced chemical changes and cementation at the surface. Such changes also are known to be associated with shallow uranium deposits and changes were looked for but not found in the thermal-inertia images; it is thought that the surface changes in this area are too minor and discontinuous to be detected from satellite.

The most consistently practical and important results involve delineation of tectonic framework elements such as lineaments bounding apparent structural blocks. These commonly can be seen even in less-than-optimal data. One pair of major thermal lineaments in the southern Powder River Basin seems to define structures not previously recognized but consistent with, and adding importantly to, an emerging story of basement-block movements and their direct influence on sedimentation, which in part controls the occurrence of large oil and gas resources. One of these lineaments matches up with aeromagnetic map data and appears to reveal a basement discontinuity which underlies the famous

Homestake Mine in the Black Hills and a zone of Tertiary igneous activity. Along with the newly identified lineaments, the thermal images also permit mapping of geomorphic textural domains. The geologic significance of these is not yet understood, but it seems likely that they connote structural and lithologic conditions which affect or control local ground-water regimes.

Similar applications of HCMM data to the Cabeza Prieta, Ariz., area illustrate the potential of using thermal-inertia data for discrimination between extrusive and intrusive rocks and for detecting differences in the mafic content of volcanics. Other results included detection of differences among surficial units - tentatively ascribed to changes in soil-moisture retention, discovery of discrepancies in existing geologic maps, and possible application of the thermal-inertia technique to mapping buried pediments.

Extension from beyond the originally proposed study areas to Yellowstone National Park was made to examine the usefulness of HCMM data in geothermal studies. Although we found that the night-thermal data could not be used with any confidence to distinguish surface hydrothermal features, we did detect additional structural information concerning the outline of the caldera which is the source of the volcanic heat. This reinforces our conclusion that a major utility of these data is in providing information about local-area or regional tectonic framework.

We have also made significant advances in modeling analysis and image-registration techniques. A thermal-inertia mapping algorithm has been developed based on a new method to derive the regional meteorologic parameters solely from the satellite data. An algorithm for determining the sensible-heat flux from ground-station data was also constructed. Simple forms for four of the atmospheric flux terms were constructed from field measurements made during circumstances when satellite data are likely to be most useful. These forms eliminate the need for extensive continuous ground station data. Also, a method to correct thermal and thermal-inertia data for elevation variations in sky and solar flux was determined. In addition, we have devised a fast topographic adjustment algorithm which can be used in conjunction with digital terrain data to correct the thermal-inertia image for simple topographic slope effects. Finally, a fast image registration technique was developed that proved to be considerably more accurate than the NASA registered products.

Our analysis of the HCMM data has resulted in the recognition of features which suggest the existence of previously unmapped and unknown geologic structures. Their relationship to other geophysical and geochemical data provides important information for a basic resource-exploration strategy. Additionally, substantial progress has been made in modeling and image-processing techniques. This report covers new areas and represents significant advances in the processing and interpretation of thermal satellite data and in the integration of thermal-infrared data in regional geologic exploration.

1.4 RECOMMENDATIONS

From our experience to date, we would recommend that serious consideration be given to a follow-on thermal satellite mission with these general characteristics.

1. The current NEΔT of HCMM seems adequate for most regional studies. Higher thermal resolution does not appear necessary.

2. Some increase in ground resolution (possibly 100-200 m) would be useful; however, there are trade-offs to consider here. The 500-m resolution from HCMM has proven very useful for regional structures - it does not appear promising for detecting alteration.

3. Some increase in the repeat times over a site is desirable. The HCMM data we have seen have often baffled us because of changing meteorologic effects. The increased repeat time would enhance the chances of "stable-clear" conditions and also provide coverage of regions under several meteorological and soil moisture conditions. The repeat time involves the orbit parameter selection; a 5-10 day repeat of coverage would be desirable.

4. The current overflight times of HCMM appear appropriate for geologic analysis. It should also be noted that the daytime maximum represents an optimum time to acquire multispectral thermal measurements as well.

5. Our analysis of HCMM data requires registration of day and night images and subsequent registration to a topographic base. The registered data provided by NASA often contained large registration errors. An essential requirement for analysis of these data is that the clear scene images be registered (day/night images) to a pixel, and to digital terrain data. If this registration accuracy cannot be achieved routinely, it is recommended that registered products <u>not</u> be provided to users.

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2.0 INTRODUCTION

The HCMM data which we have examined have provided us with unique geologic information which is both complex to analyze and difficult to explain. In some cases we are astonished to see subtle distinctions of structure and geologic materials that are not found on detailed geologic maps. In other cases we are unable to differentiate widely dissimilar geologic materials or identify features which are clearly described on regional geologic maps or Landsat images. Commonly, geologic features are clearly displayed on a single image or part of an image and not on others. Further complicating the analysis of these data has been the experimental nature of the satellite mission, which has introduced both significant time lags between data acquisition and interpretation, and unique constraints in image registration and data calibration.

This report comprises pieces to a puzzle--a puzzle with tantalizing new information but sufficient gaps to preclude a complete overall assessment. We have examined the geologic implications of the HCMM data in the Powder River Basin of Wyoming and subsequently extended the analysis to the Cabeza Prieta area in Arizona. Enhanced nighttime images, thermal-inertia images based on our new algorithm, and several profiles of various data across the basin are presented in our analysis and subsequently compared with other map data (geologic, magnetic field, known areas of oil, gas, and uranium occurrence, helium anomalies, and ground water). Of equal importance with the geologic interpretation has been progress in modeling. We provide several new algorithms: thermal-inertia mapping, estimation of regional meteorological information from the fundamental remote sensing data, registration of satellite day-night images, elevation correction of thermal and thermal-inertia data, and determination of sensible-heat flux. The concluding section of this report addresses our image processing techniques together with a listing of the computer programs used.

2.1 GEOLOGIC SETTING

The study areas are the Powder River Basin and environs in eastern Wyoming-Montana and the adjacent Dakotas and the Cabeza Prieta Range in southwest Arizona. The Powder River Basin (lat. 42°-45° N., long. 103°-107° W.) has large potential for coal, oil and gas, and uranium, and accordingly is now the target of several major geologic, water-resource, and land-use mapping projects. Covering an area of about 250 x 400 km, it is a semi-arid region of rolling low hills typically with thin to moderate grass and sage cover. Tertiary rock units (Fort Union and Wasatch Formations) in the central area of the basin, where the energy resources are known to occur, are exposed on scales sufficient for satellite measurements. The lower part of the Fort Union is sandstone exposed in belts 4 to 10 km wide; the upper Fort Union part is siltstone with major coal beds exposed in belts 10 to 30 km wide; and the Wasatch is siltstone and claystone covering areas 30 to 60 km wide.

The Cabeza Prieta Range in Arizona (lat. 32°-33° N., long. 112°-115° W.) is a proposed Wilderness area, and the USGS has begun a program to define the geology and mineral-resource potential of this virtually unmapped area. The State geologic map shows the area to contain granite, schist, mafic volcanic rocks, and alluvium. It lies very near the major mineral district at Ajo, Ariz., and contains old prospect developments in hydrothermally altered ground. Because the area has been withdrawn from public access since World War II, the geology and mineral potential are barely known and thus the area is considered relatively important for modern study.

2.2. APPROACH

Initial data interpretation was performed by visual pattern recognition of areas significantly different than their surroundings. Several 1:1,000,000-scale photographic enlargements were made of the NASA thermal and reflectance images to match them to many of the other existing data map products (geologic, geophysical, topographic, Landsat lineaments, and so on). Because of the X-Y distortion and the large magnification, this method was not entirely satisfactory for detailed study. We then generated film products from the computer-compatible tapes (CCT's) and used a zoom transferscope with X-Y stretch capability to register the projected images onto a stream-network map. In most local areas, this permitted plotting of features to within one to three pixels of their true ground position. Few of the interpretations based on the temperature boundaries or on other features are significantly affected by this degree of mislocation.

During this stage of the investigation, we also discovered that the NASA-supplied ΔT and thermal-inertia images contained artifacts, such as double drainage, indicating misregistration in parts of these images of several to many pixels. Consequently we developed a registration algorithm (Watson and others, 1981b) which registers data to within two pixels. Also as part of the investigation, we developed a new thermal-inertia algorithm (Watson, 1981a) which was employed during the remainder of our analysis. Correlation of these registered image products with the other geologic-geophysical data was performed primarily by using optically enlarged projections of the data on digitally enlarged image product at a scale of approximately 1:200,000. This enabled us to examine subtle features at the pixel level and also to employ our full profiling and histogram capability at the full dynamic range and resolution of the digital image data. We have thus been able to quantify many of the scene differences which had been observed on various image products.

We also examined the use of color-coded images for enhancing subtleties in the scene contrast. Generally this provided a more obvious demonstration of differences but did not appear to add any new information. Toward the end of our study, however, a color-coded thermal-inertia image was produced which provided a new - if unexplained - perspective of the scene. A north-northeast-trending rectangular pattern of ground, surrounding the Black Hills and roughly corresponding with major changes in the drainages of the Yellowstone and Missouri Rivers was observed In retrospect, this feature can now also be seen on the black and white products. The color-coding of the image was also a very useful tool for quickly determining the numerical range of values. With an appropriate color-scale and using a high-powered magnification lens, it was possible to determine the thermal-inertia ranges of many geologic units quickly. In both these respects the color-coding can be regarded as a useful but not essential element in the analysis.

2.3 RESULTS

2.3.1 Thermal-inertia mapping for discrimination of geologic features

2.3.1.1 Delineation and subdivision of geologic units

Discrimination studies have been somewhat limited by the lack of sequential day-night image pairs free of major atmospheric/weather problems, but the 20 August 1978 set of day (AA0116-20010-1,2 and AA0116-20020-1,2) and night (AA0116-09040-3) scenes and our constructed temperature-difference (ΔT) and thermal-inertia images show several geologically significant features. Other good nighttime data from 30 July 1978 (AA0095-09170-3), 5 September 1978 (AA0132-09050-3), 27 September 1978 (AA0154-09190-3), and 10 June 1979 (AA0410-08450-3) passes have been used for delineation of several geologic boundaries, including some not within the area of, or not identified in, the 20 August 1978 data set.

A measure of discrimination capability, using optimal images and selection of geologic units which contrast well with their surroundings, is the clear delineation of the Mesaverde Formation. South of the Bighorn Mountains, in the vicinity of the towns of Midwest and Edgerton Wyo., the Mesaverde - a relatively massive sandstone - crops out between the Fox Hills Sandstone and the Cody Shale. On the night image (fig. 1) for 30 July 1978, all three units are relatively warm; however, the Mesaverde can be traced as a distinctly warmer unit ($1/4^{o}$-$1/2^{o}$ C), along at least 40 km of strike length in which a fold nose is clearly defined (fig. 2). The Mesaverde outcrop here is 1-2 km wide or 2-4 resolution elements (pixels).

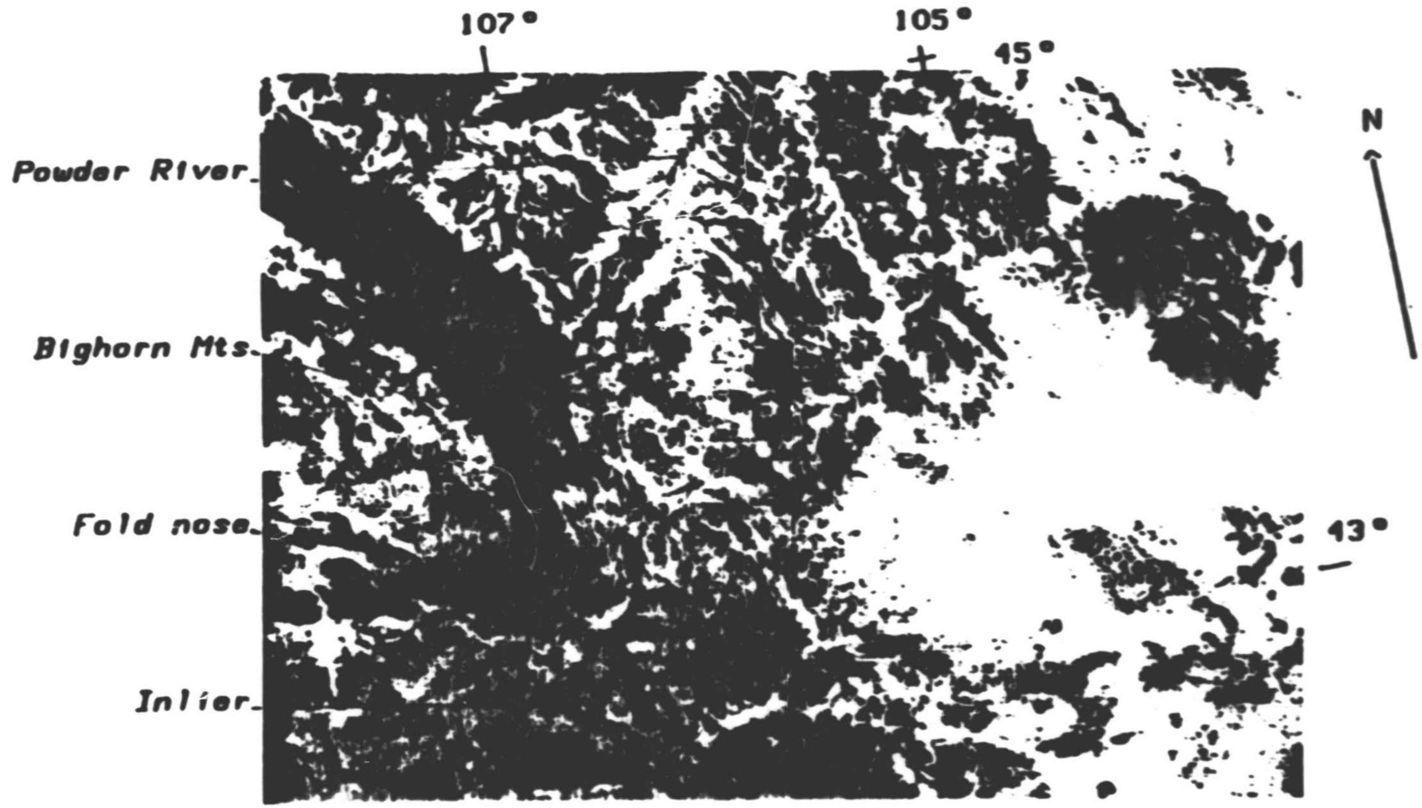


Figure 1.-- Night thermal image, July 30, 1978, of the Powder River Basin, Wyo., delineating the fold nose of the Mesaverde and the Frontier inlier. The standard convention of dark for low values and light for high values is employed on all images in this report.

0 100 Km

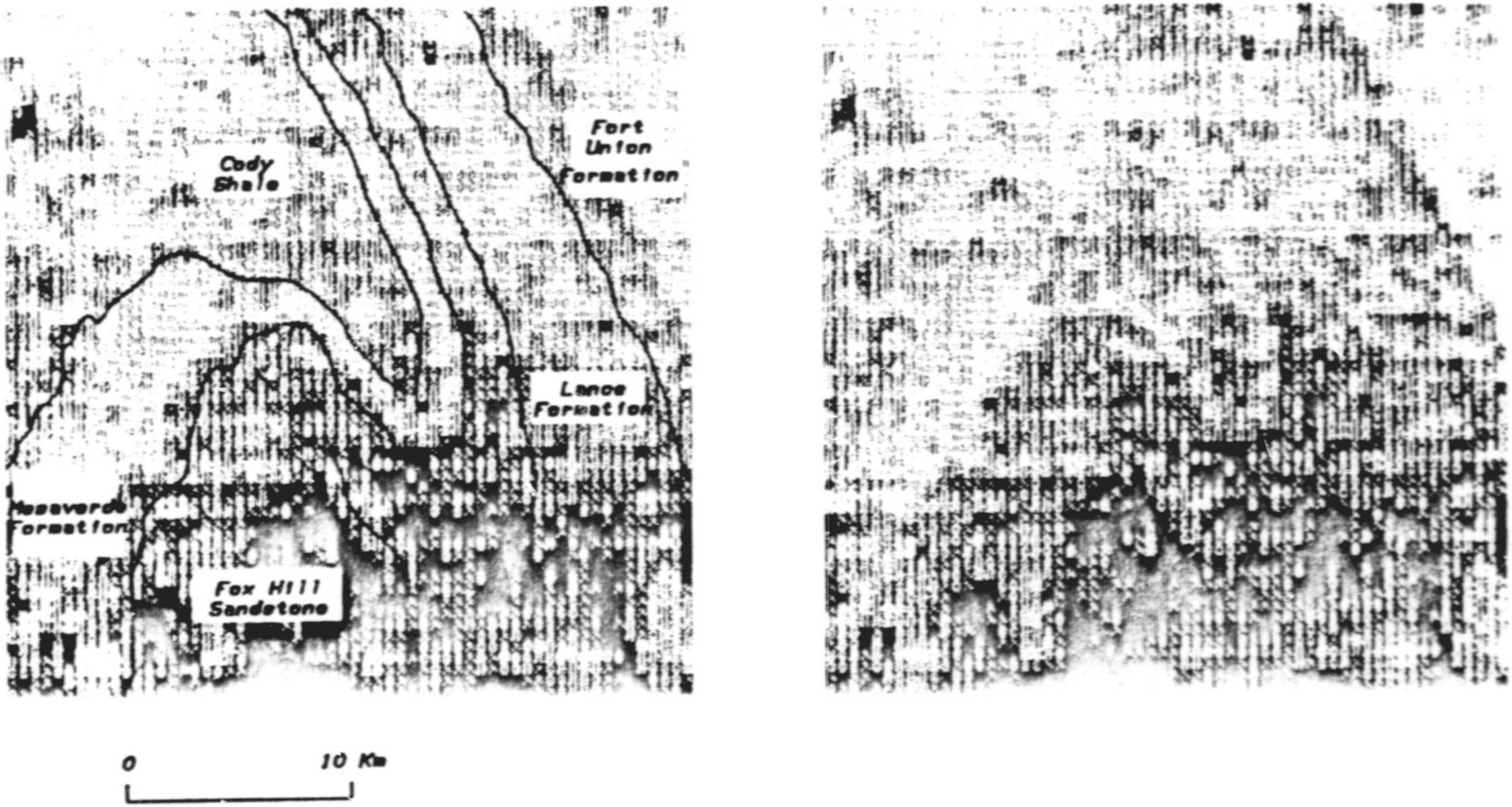


Figure 2.— Fold nose of the Mesaverde Formation as expressed on the July 30, 1978, nighttime HCMM image. An unmarked image is provided for comparison.

Southwest of that area, south of the town of Powder River, within a large area of Cody Shale, is a sandstone inlier of Frontier Formation surrounding older shale and sandstone of the Cloverly and Morrison Formations. In the 30 July image, the Frontier is clearly a warm annulus around a cool center of the other units (fig. 1 and 3). The units in the cool central area are about 5 km wide and the warm Frontier annulus is 3.5 km wide. What is additionally interesting in this area is the apparently clear definition of a similar but smaller such feature to the northwest which does not match the shape of the contacts on the most recent geologic map (Love and others, compilers, 1955). This feature has not been field checked.

Another measure of discrimination is found in the area of the Pumpkin Buttes. These are very sharply defined in the 5 September 1978 night image (fig. 4). North Butte is about 3 km wide, and the combined topographic/geologic prominence of Middle and South Buttes measures about 4 by 8 km. These are warmer than their surroundings, as is expected of tuffaceous sandstones of the White River Formation, dense and resistant enough to form buttes where erosional remnants lie upon the softer sandstones and mudstones of the Wasatch Formation. Once again, when the geologic map was projected onto this HCMM scene, differences were observed. Unfortunately, on our only thermal-inertia image, clouds were present over the Buttes preventing the observation of the expected thermal-inertia contrast.

Definition of geologic features is highly variable from pass to pass and within single passes. The 30 July image (fig. 1) is excellent for the north half of the Powder River Basin and the areas west and southwest of the Basin. The image appears virtually washed out in the south half of the Basin,

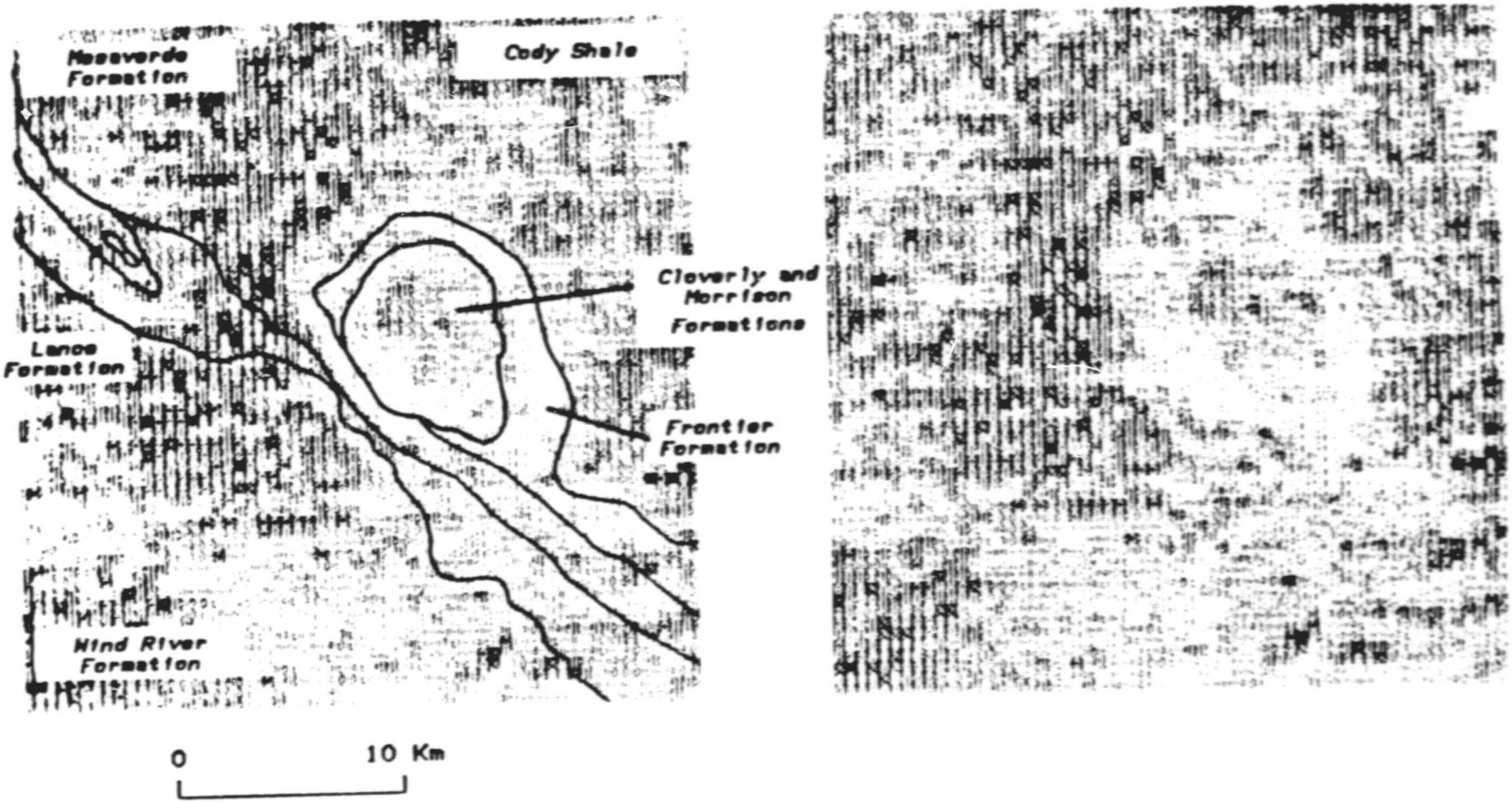


Figure 3.-- Inlier of the Frontier Formation as expressed on the July 30, 1978, nighttime HCMM image. An unmarked image is provided for comparison.

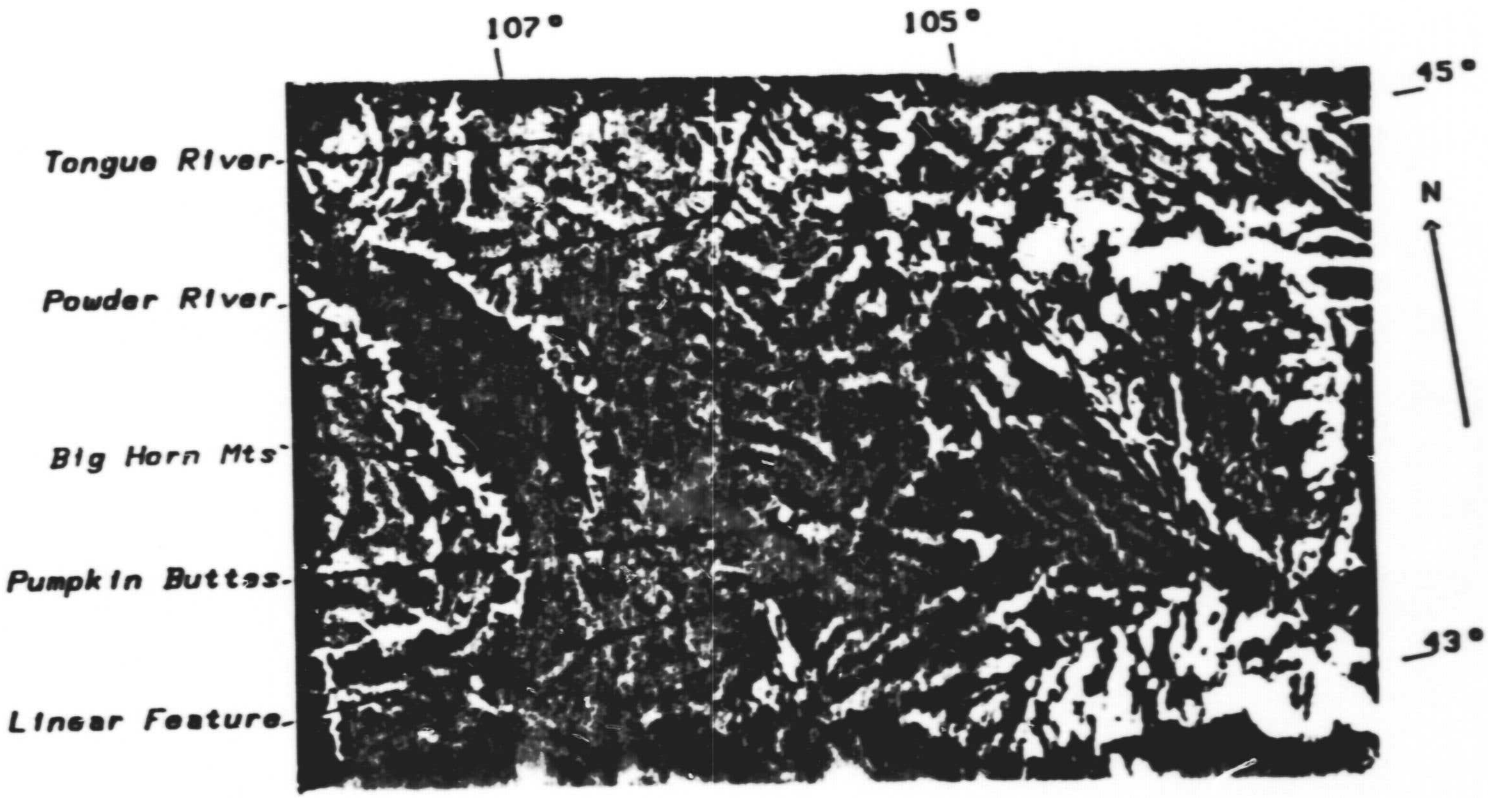


Figure 4.-- Night thermal image, September 5, 1978, of the Powder River Basin, Wyo., showing the descrimination of the Pumpkin Buttes.

0 100 Km

showing high temperatures in an area conspicuously cool in all the other images. Because the image was examined long after it was acquired, it was not possible to obtain detailed field meteorological data. This is a generic problem in dealing with transient and local phenomena that commonly affect thermal surveys. Air temperature and precipitation data show fairly similar conditions at the 28 weather stations throughout the scene. From these data, the intrascene variations cannot readily be ascribed to local weather/moisture changes; however, the NOAA and DMSP (Defense Meteorological Satellite Program) Satellite data show that a major weather front had recently passed through the basin. Such intrascene differences are less pronounced or even absent in other passes, but none of the others expresses quite the same degree of geologic feature definition as the good portions of the 30 July image.

The multiple data sets of 20 August contain considerable geologic information, especially in comparing patterns seen variously in the day thermal, night thermal, ΔT, and thermal-inertia images. The day thermal image (fig. 5) shows large areas of warm ground north and east of the Black Hills. These do not correspond to lithologic subdivisions on any available geologic maps, nor to any patterns of weather across the scene during the previous few days. Small individual features of interest in the image are cool areas around the Tongue River and in a belt of small patches trending north-south up the center of the southern part of the basin. The very warm drainage area west of the Black Hills and the warm area south of the Black Hills are also noteworthy. The night image (fig. 6) offers busier patterns of finer scale definition, dominantly related to the topographic character of local areas. Much, but not all of the high ground between streams, is conspicuously warm. The long,

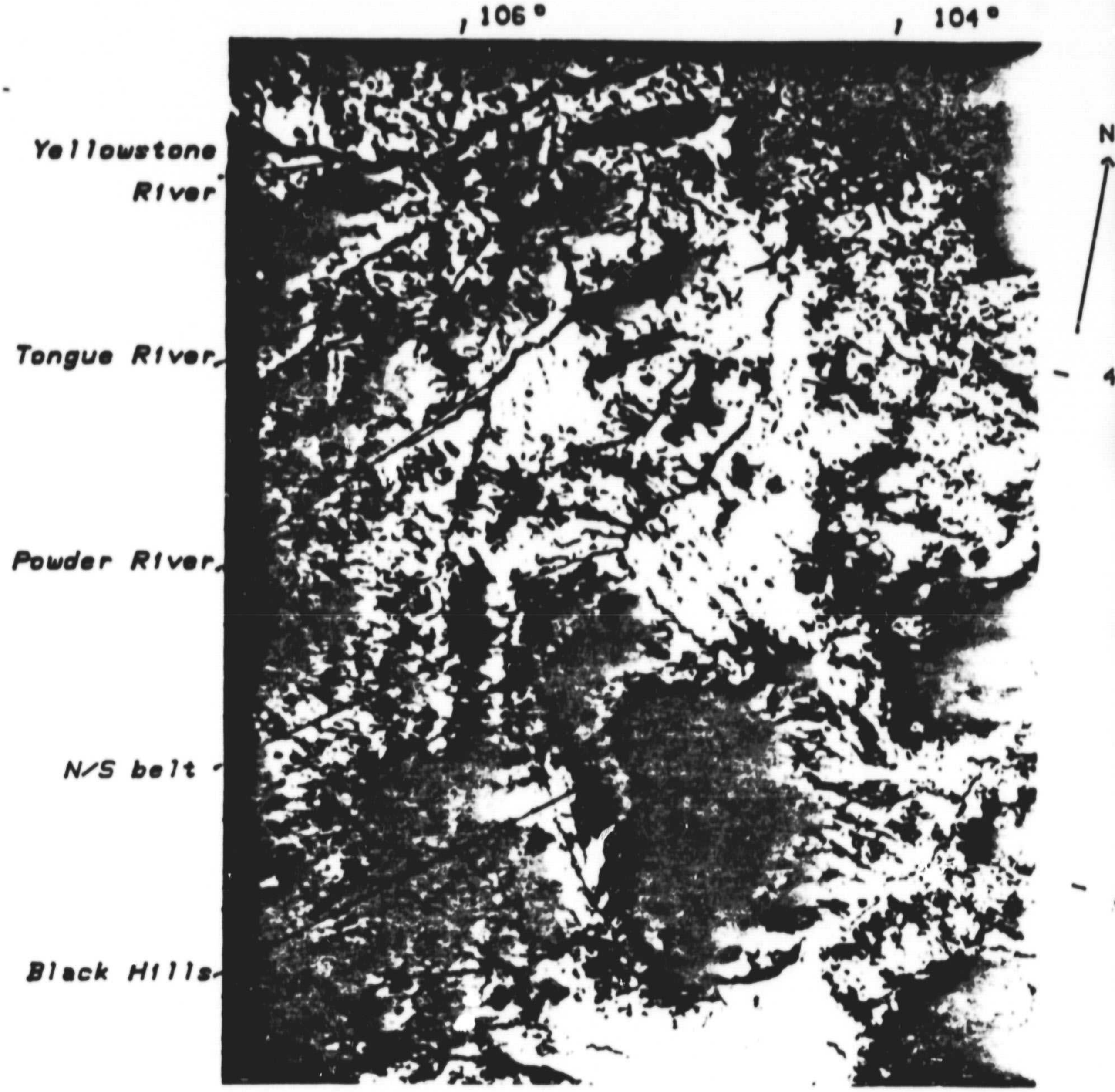


Figure 5.-- Day thermal image, August 20, 1978, of the Powder River Basin, Wyo., showing thermal boundaries.

0 100 Km

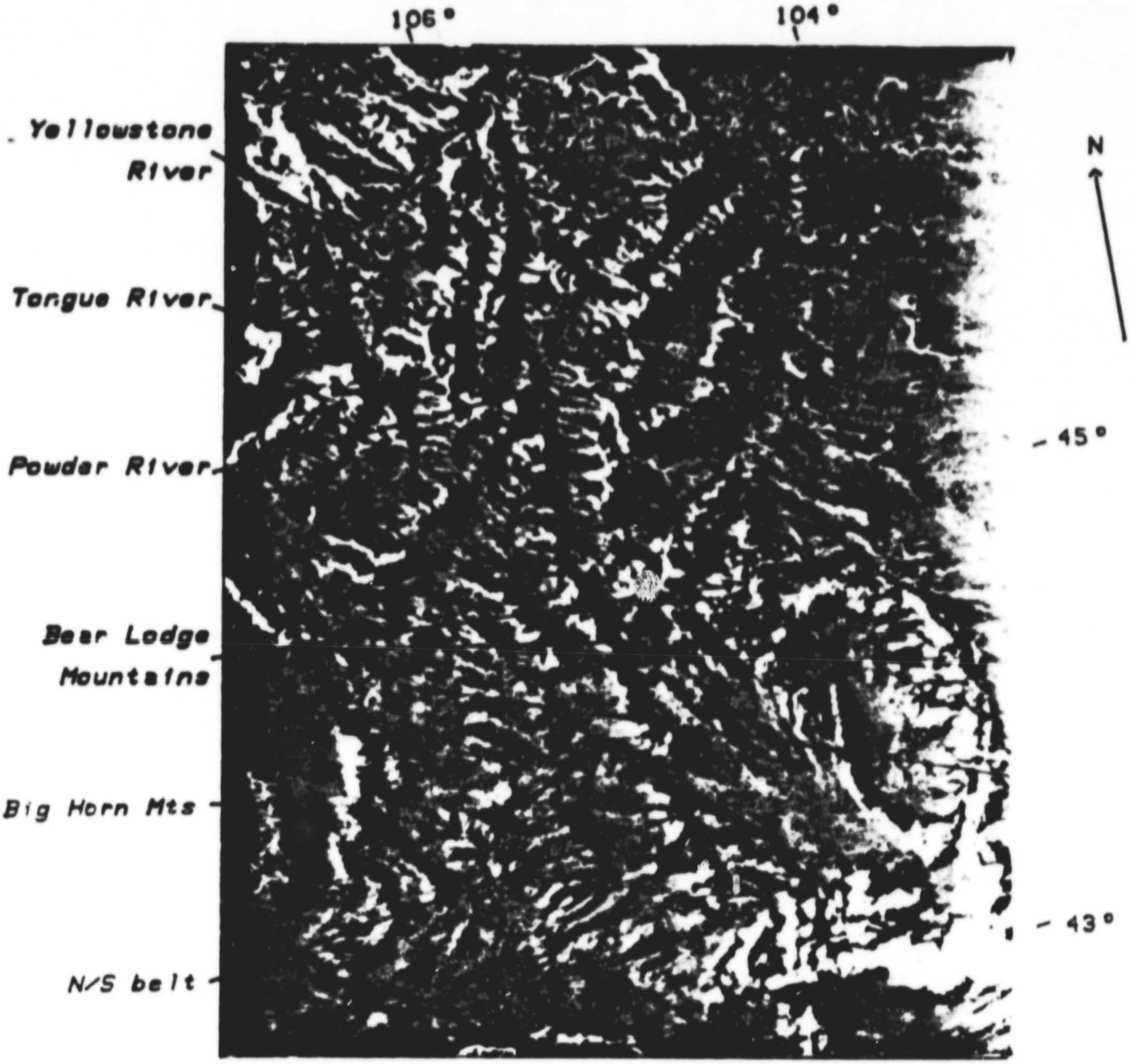


Figure 6.-- Night thermal image, August 20, 1978, of the Powder River Basin, Wyo., showing the conspicuously warm areas. The unlabeled lines are profiles A-A' (north line) and B-B' (south line).

0 100 Km

straight Powder River separates warm ground on its east flank from cooler ground on its west flank. This is not just an effect of east- _vs._ west-facing slopes, because most other stream areas do not show the same effect. The north-south belt in the southern part of the Basin shows as very warm patches of ground. Very warm areas ring the east flank of the Black Hills and occur just to the north throughout the Bear Lodge Mountains, but these do not correspond to the mapped geology. Other contrast stretches were tried including color slicing but the correlations of temperature areas with geology did not improve. What does appear to be true, however, is that within the Powder River Basin, conspicuously warm areas are much more abundant in the north half. For the most part, this is a result of greater dissection of the terrain and more exposure of bedrock, as compared with few outcrops and abundant windblown sand veneer in the south half.

Analysis of the thermal-inertia images, derived from our registration and modeling algorithms, showed that the Tongue River areas of cold ground in daytime are, in fact, areas of high thermal inertia (2000 Thermal inertia units (TIU); 1 TIU = 1 W $sec^{1/2}$ m^{-2}). These areas (fig. 7) correspond quite well to areas mapped by Raines (Raines and others, 1978), using computer enhancements of Landsat images. They were mapped as the coarsest, sandiest lithofacies unit in the basin, which are relatively indurated and resistant and should crop out best and, depending on moisture conditions, should have the highest thermal inertia of the subunits in the Wasatch and Fort Union Formations. Other such correlations exist for several areas of this facies southeastward toward the Black Hills. Areas of the Wasatch and Fort Union, sampled from various parts of the Basin and which appear to be representative

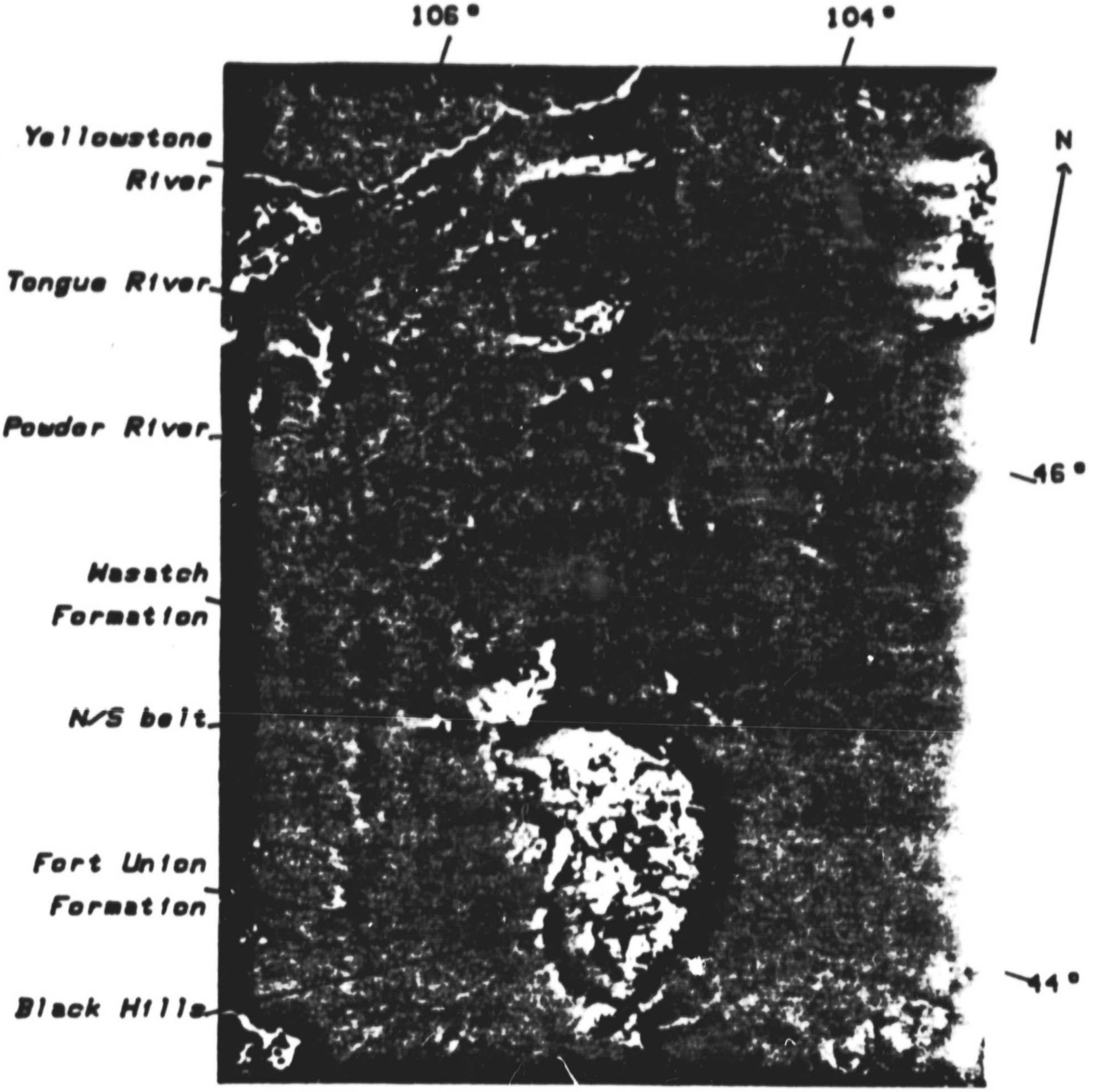


Figure 7.—— Thermal-inertia image, August 20, 1978, of the Powder River Basin, Wyo.

0 100 Km

of larger surrounding areas have thermal-inertias of 1525 TIU and 1450 TIU, respectively. However, the thermal-inertia of these two units varies considerably throughout the basin and in some cases values for these two units are statistically inseparable. A possible explanation is that these units generally form low or flat topography where windblown sand obscures the underlying geology in extremely irregular (and unmapped) patterns. Another reason is that these units retain moisture differently and longer than sandier facies, and thus may have great irregularities in both thermal-inertia values and wind cooling patterns. If they are slightly wet, and not cooled by surface winds, their thermal inertia will be higher.

The north-south belt of high thermal inertia (fig. 7) was initially thought to correspond to burned ground over ancient natural coal fires. The night thermal image (fig. 4) was carefully registered to a base map and a composite map was made showing the areas of clinkers (as determined from a color ratio composite Landsat image) and the warm areas on the HCMM image (fig. 8a). We then examined the thermal-inertia image and determined that the clinker areas in fact have an intermediate thermal inertia (1300 TIU) and the N-S belt of warm ground in the night image just east of the clinker hills has a higher thermal inertia (1500 TIU). This north-south belt has been mapped in detail and the surface geology provides no clue as to why these areas have high thermal inertia. This does not conform with conditions produced where windblown sand accumulates in the lee of topographic highs. It is suspected that the highly fractured clinker hills are readily drained of their near-surface moisture and this ground water tends to pond just eastward in the direction of normal drainage, causing an increase in thermal inertia. This

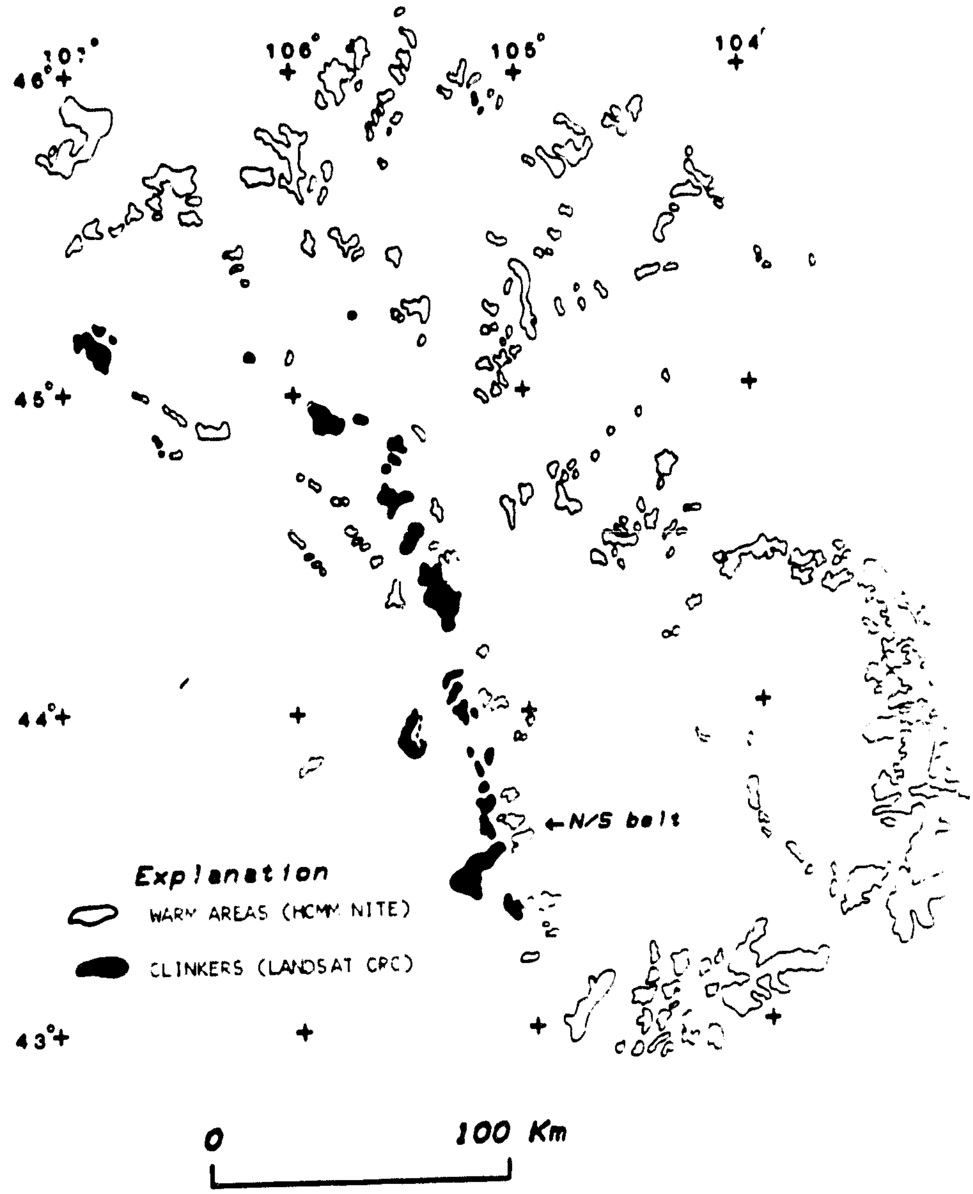


Figure 8a.-- Base map of the Powder River Basin, Wyo., showing the location of the clinkers with respect to the warm areas which have high thermal inertias.

hypothesis is given credence by an examination of the NURE gamma-ray profiles in this area. These areas coincide with lows in the total gamma-ray measurements (fig. 8b) as would be expected for areas of higher moisture content.

A rough order of magnitude estimate from these data is that the anomalous areas are associated with a 20 percent increase in thermal inertia and a 5 to 10 percent decrease in the total count values. The thermal inertia of soils increases rapidly with increasing soil moisture content and the effect can be estimated for low moisture contents by considering only that increase due to density and specific heat capacity. The ratio of the fractional change in thermal inertia to density is just one half the ratio of the specific heat capacity of water to soil or approximately 2.5. Thus a 20 percent increase in thermal inertia could be produced by a soil moisture change which increases the density by 8 percent (and decreases the total count by an equivalent percent).

To examine the basin further, two northwest-southeast profiles across the 20 August image (fig. 6, profiles A-A', B-B') were constructed. These profiles enabled us to look in detail (pixel level) at variations in thermal-inertia values and to examine relationships between temperature or thermal-inertia patterns and topography. Topographic data were taken from 1:250,000 USGS base maps with a contour interval of 200 feet. Figures 9 through 14 show profiles of thermal-inertia, elevation, and topographic gradient along lines A-A' and B-B'.

The profiles on A-A' have several interesting features. The line begins in the Wasatch Formation at the northwest end, and thermal-inertia values (fig. 9) decline into a broad low, about coincident with the Powder River

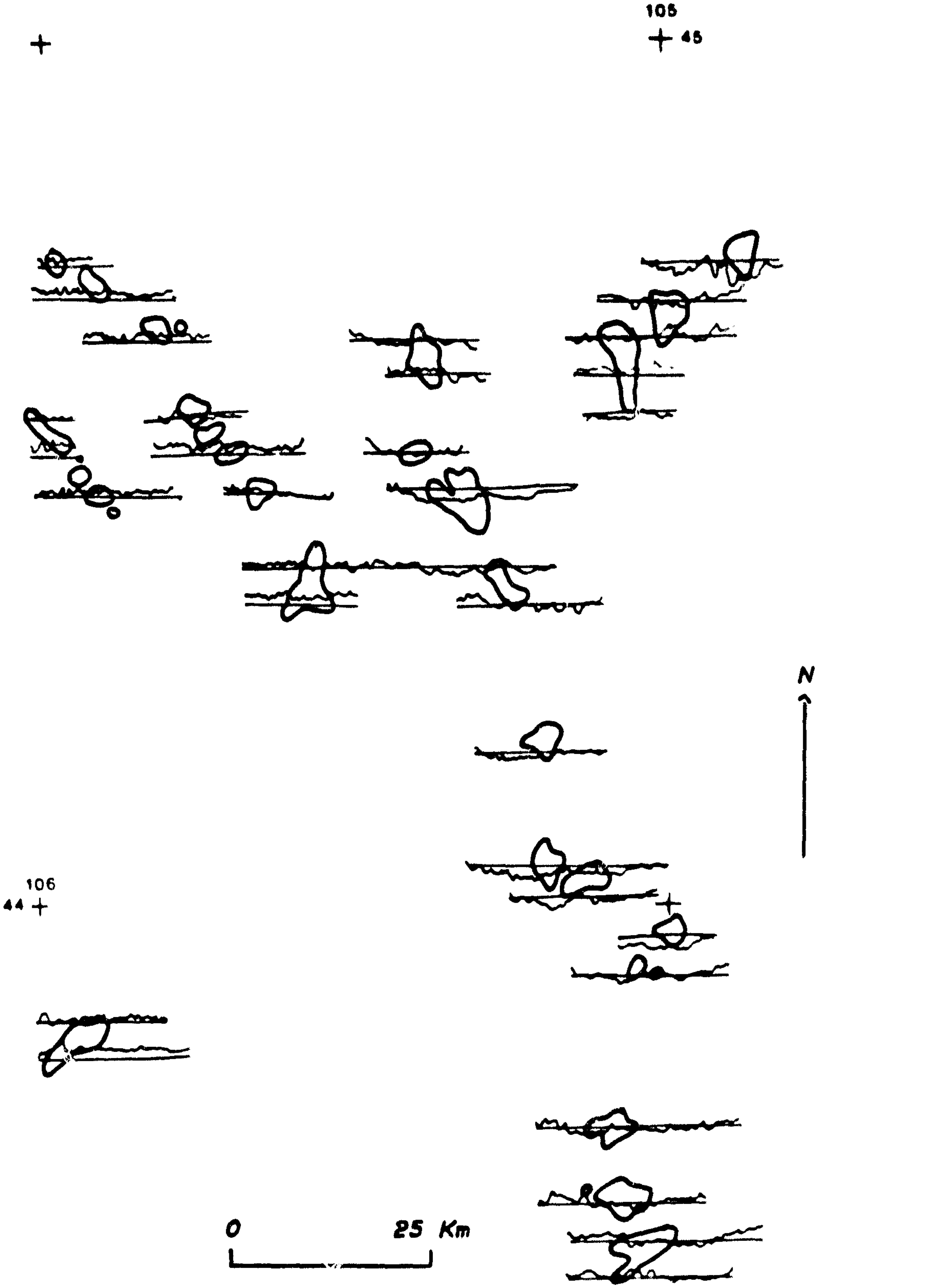


Figure 8b.-- Comparison between profiles of total count gamma ray and the anomalously warm areas. The straight lines indicate the geographic position of the profiles.

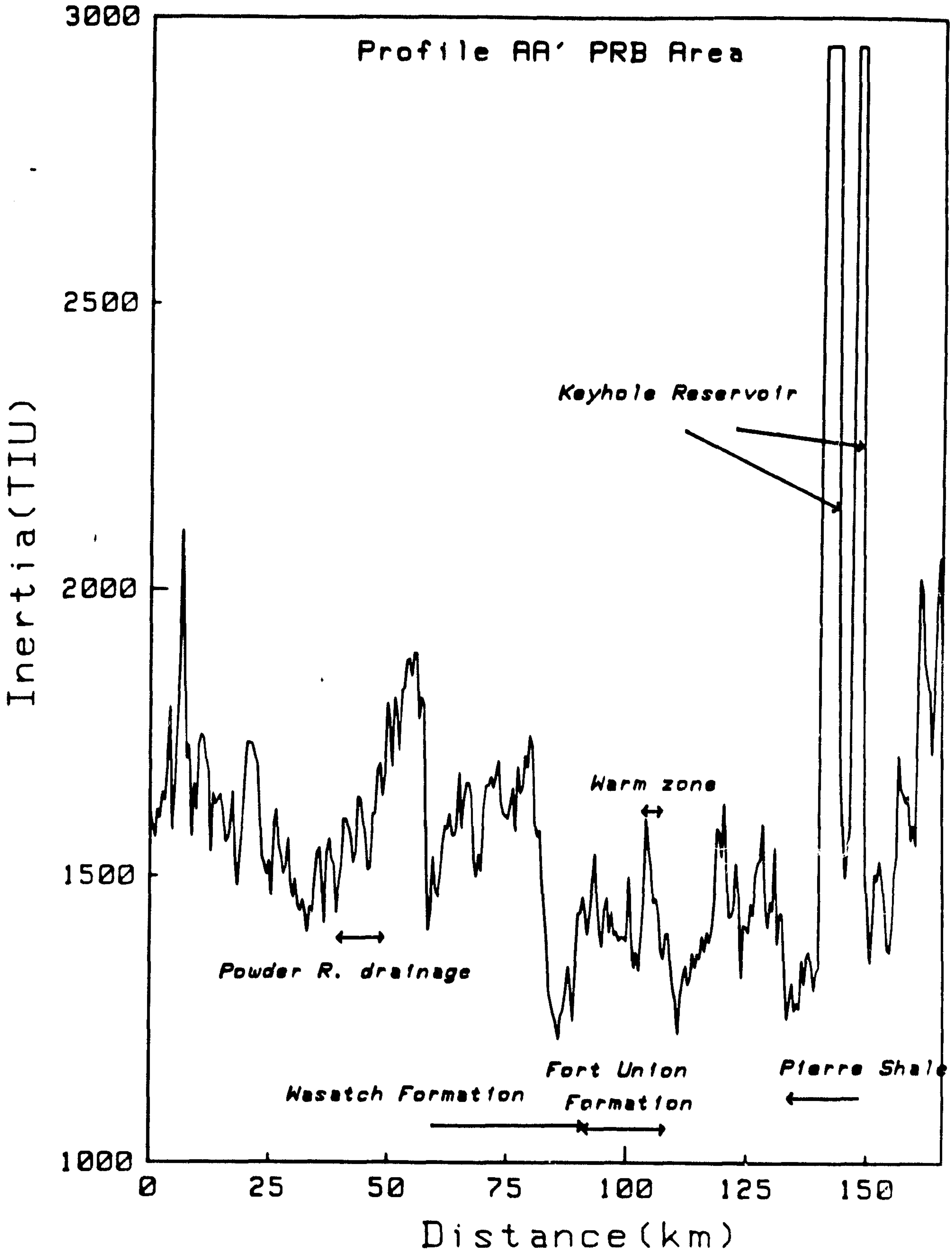


Figure 9.-- Thermal-inertia profile for line A-A'.

drainage seen so clearly in the topographic profile (fig. 10, 11), and then rise. This low approximately marks the basin axis, and the adjacent slopes of the thermal-inertia profile show the character of the upper part of the Wasatch on either side of that axis. The topography itself is somewhat different on opposite flanks of the Powder River drainage, and this probably explains the previous observation that the night-temperature image showed the two flanks differently, even though the thermal-inertia image indicated the two flanks to be underlain by similar material. The flanks have different slopes and bed dips, and the western flank generally is dissected more sharply and deeply than the eastern flank. At the next large drainage east of the Powder River, the thermal-inertia profile breaks sharply, suggesting either a previously unmapped lower unit of the Wasatch or a sharp change to the somewhat finer grained facies which has been noted in the lower part of the formation. Along this profile the Fort Union Formation has a roughly estimated average value of 1425 TIU, as compared with an equally rough, general average of the Wasatch of 1625 TIU. This difference is about what would be expected from the compositions of the two formations, although they are rather nonuniform on the scale of the whole basin. The "typical" areas of Fort Union and Wasatch that were sampled gave values of 1450 TIU and 1525 TIU, respectively. A sharp break in the thermal-inertia profile occurs between the two formations, but it falls 4 to 5 km west of the contact as shown on the geologic map. A break or dip also occurs in the profile at the contact of the upper (Lebo Shale) and lower (Tullock) members of the Fort Union, but overall the members have about the same thermal inertia. The elevation profile shows a marked change in character of topography from Wasatch to Fort Union, as does

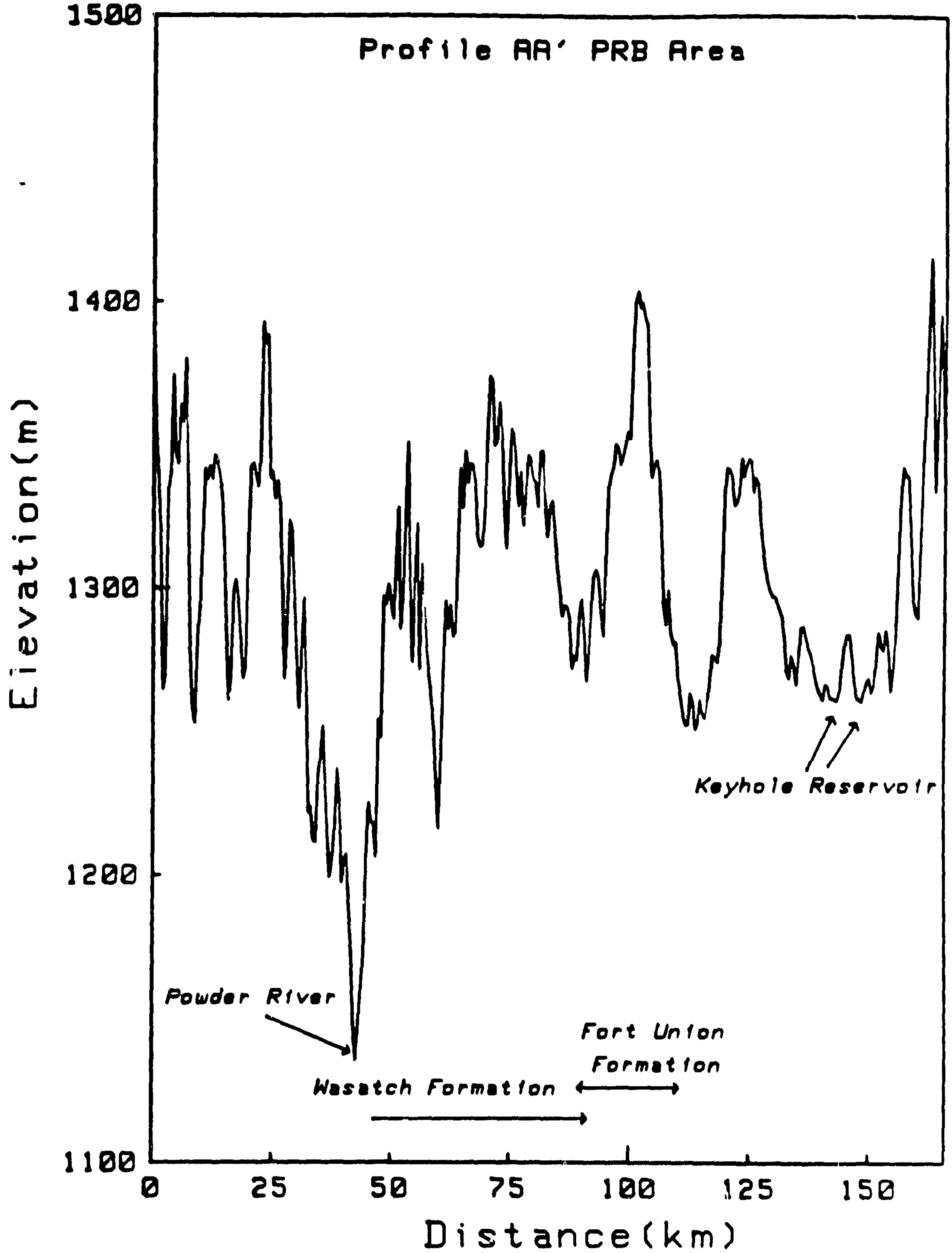


Figure 10.-- Elevation profile for line A-A'.

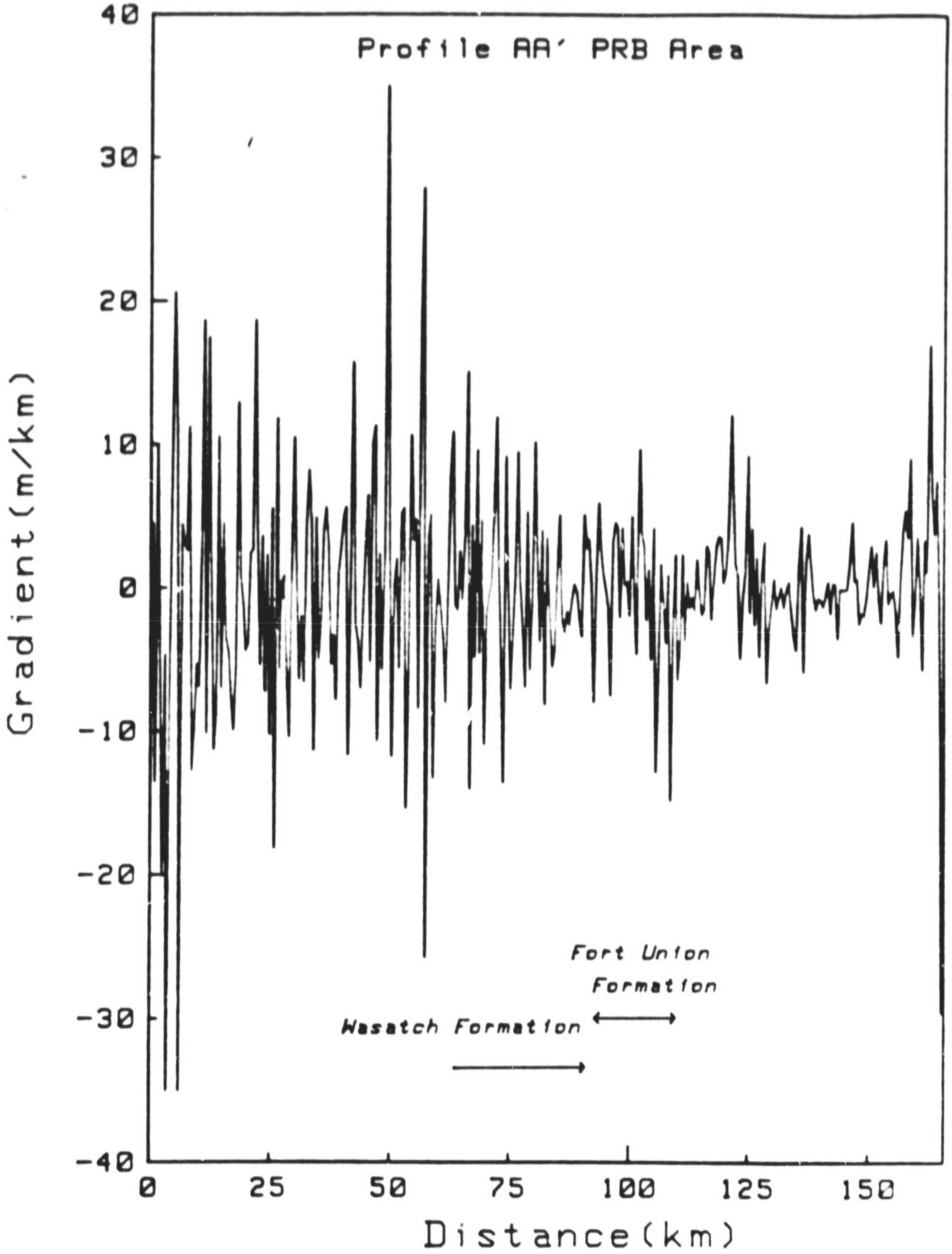


Figure 11.-- Topographic-gradient profile for line A-A′.

the topographic-gradient profile. The warm north-south zone is a narrow but prominent thermal-inertia spike in the lower part of the Lebo Shale Member of the Fort Union. The Pierre Shale has the lowest thermal-inertia of any units along the profile (about 1330 TIU), in huge contrast with the adjacent spikes which mark Keyhole Reservoir.

Line B-B' presents a rather different character in the profiles. The Wasatch thermal inertia (fig. 12) is not at all like that on line A-A'; most of its width on line B-B' is an area of unexplainedly low values which mark a very distinctive and nonrepresentative area within the widespread formation. Wasatch with relatively normal-appearing thermal-inertia image character appears next to the cloud area at the northwest end of the line; there its estimated average thermal inertia is 1550 TIU, only 5 percent different from that seen on line A-A'. The area of low values does not appear to be related to microclimatic factors, nor to any geologic feature of which we are aware. For example, neither here nor elsewhere in the image area do thermal-inertia values closely and consistently correspond with the inferred lithofacies areas delineated in Landsat images. On this line, the Lebo Shale Member of the Fort Union has a roughly estimated thermal inertia of 1750 TIU, higher than the representative Wasatch values. Most of this is in the broadest part of the north-south warm zone, however, so the values almost certainly do not represent normal character. The Tullock Member of the Fort Union is estimated at 1300 TIU, almost 10 percent lower than the Fort Union of line A-A'. Such a change is believed to be both real and significant in terms of the geology, but no data are available as to possible lithologic changes of the unit between the two profile areas. The Pierre Shale has a thermal inertia of 1260

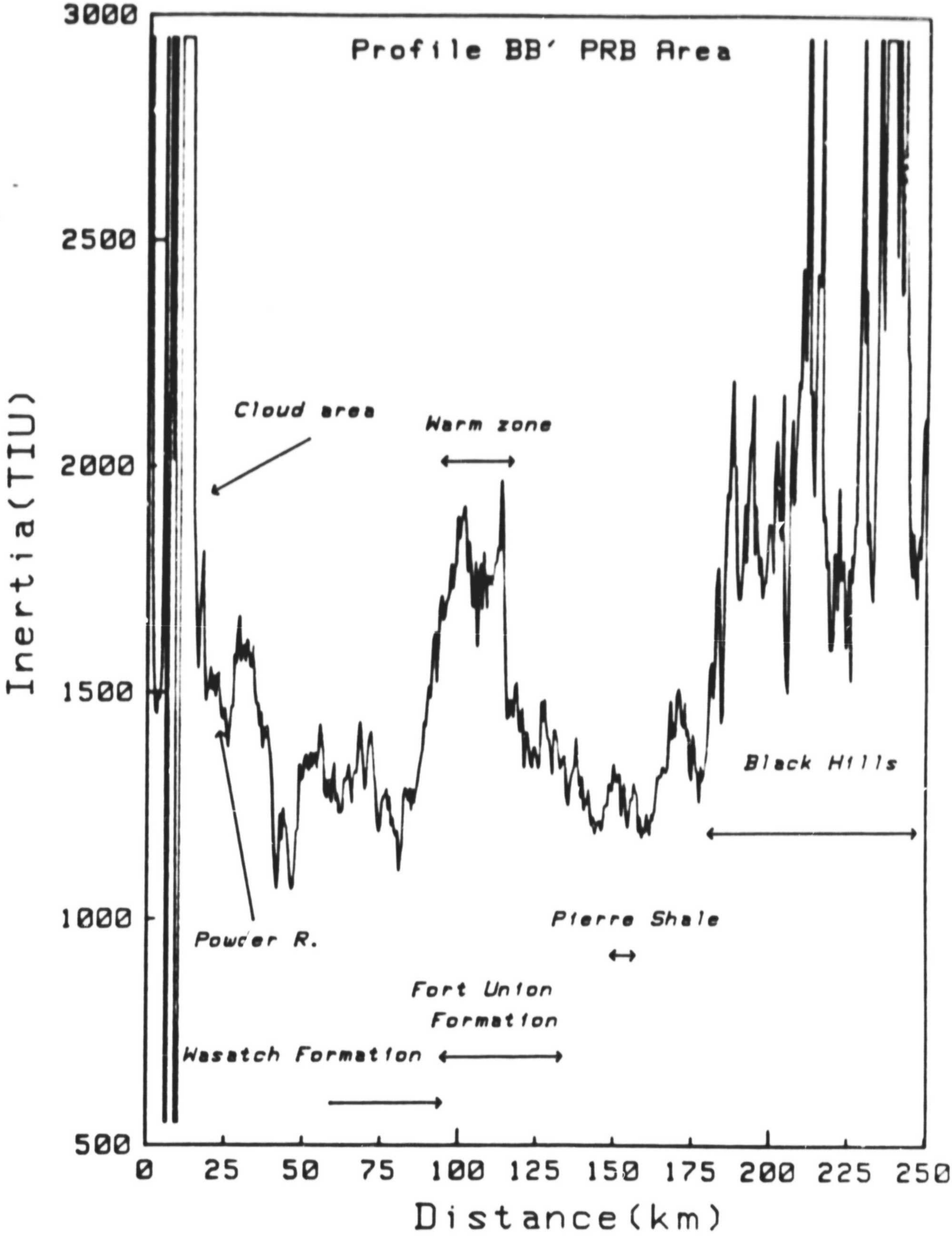


Figure 12.-- Thermal_inertia profile for line B-B′.

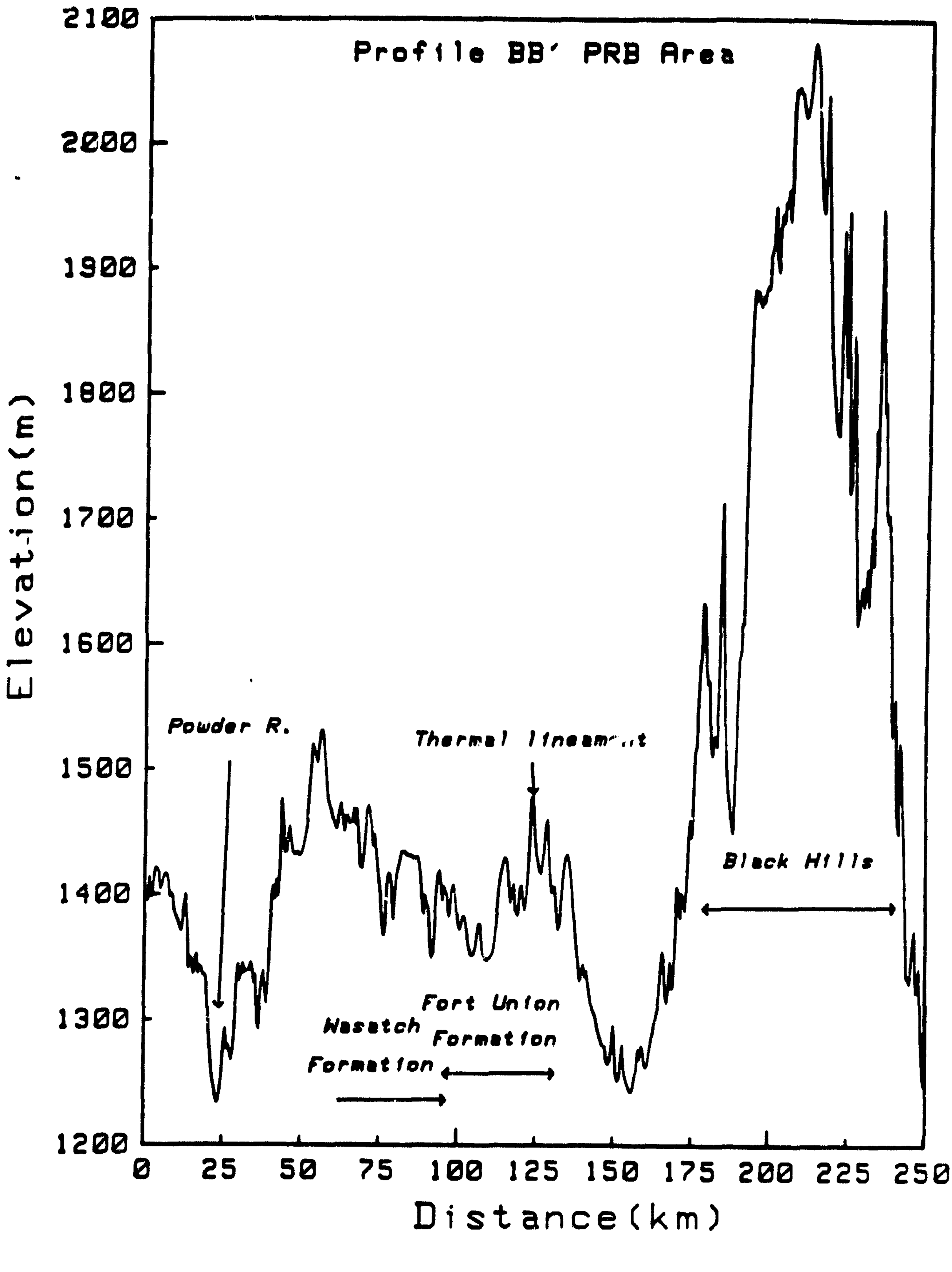


Figure 13.-- Elevation profile for line B-B′.

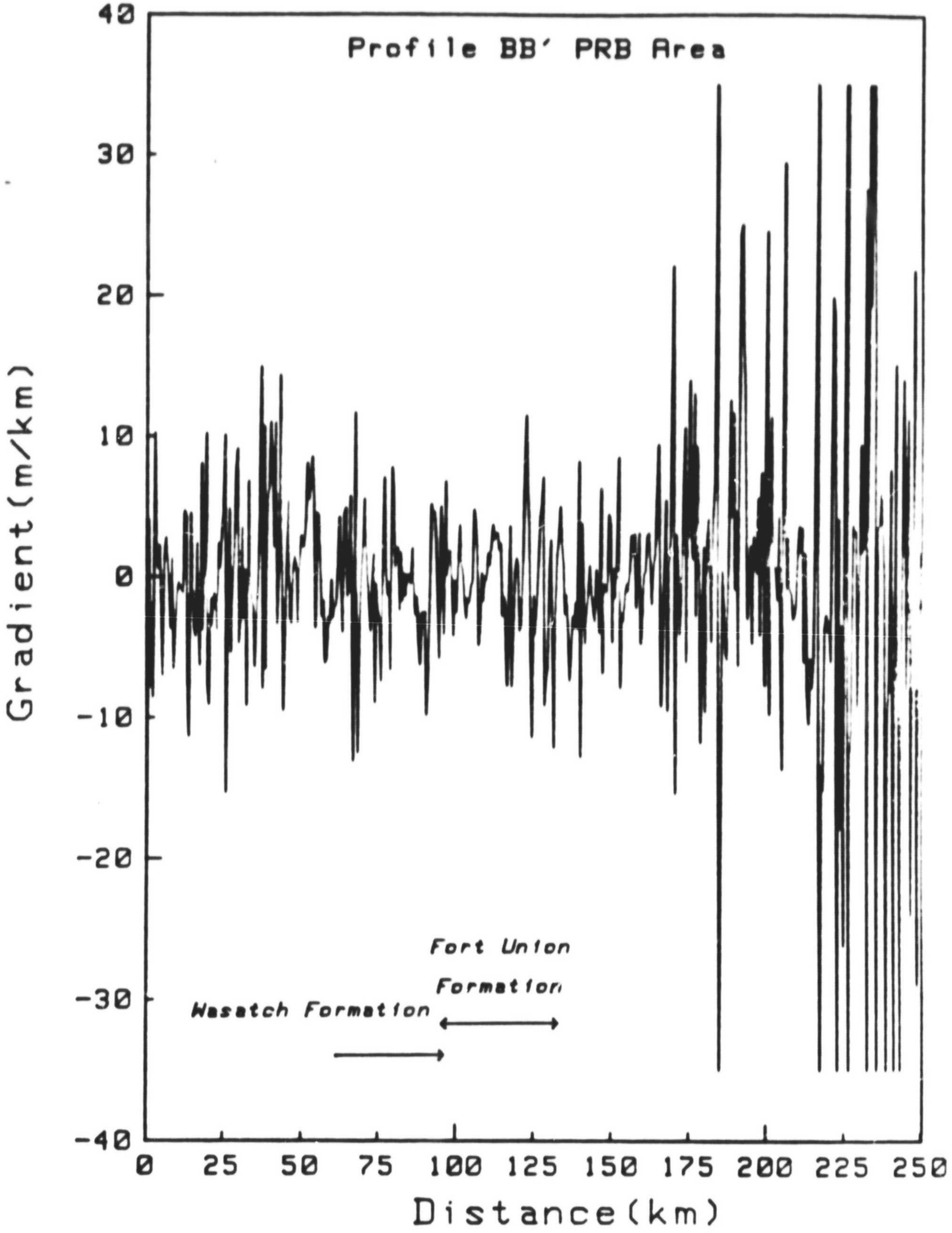


Figure 14.-- Topographic-gradient profile for line B-B′.

TIU, about 5 percent less than observed on line A-A', and again the lowest values of any geologic units on the profile. High and highly variable thermal inertia is seen in the Black Hills portion of the profile as expected in an area of alternating high vegetation density and bare rock exposures.

From this analysis, it appears that thermal data, especially when coupled with topographic information, can aid materially in discriminating geologic formation and member differences, even (as in the Powder River Basin) where units are so variable and exposures so poor that geologists have had real problems or have been unsuccessful in such efforts. It appears that thermal-inertia differences of perhaps as little as 5 percent, and certainly 10-15 percent, can be delineated and used in mapping, probably in terms of both rock units and generalized soils characteristics. So far, patterns seen in thermal-inertia images do not match with vegetation patterns seen in Landsat images and believed to correspond to subtle facies differences. This problem needs further investigation; it may relate to difference in resolution of the two satellites and to differences in depths "seen" by thermal-inertia measurements and vegetation root systems.

2.3.1.2 Geomorphic domains and linear features

An interesting and important aspect of using thermal-inertia images is that erroneous impressions gained from temperature patterns are corrected and a truer picture of surface properties obtained. This is particularly true of night thermal data. For example, the very warm zone around the Black Hills in the night image (fig. 6) disappears in the thermal-inertia image (fig. 7), and a whole new pattern emerges. The contrast of opposite flanks of the Powder

River also disappears, indicating no basic difference in geologic materials across the river. Thus we can use thermal, albedo, and thermal-inertia data in concert to separate physical properties differences (integrated over the top decimeter of the soil or rock profile) from those effects due to such parameters as slope, altitude, and surface reflectance.

For the units underlying most of the Powder River Basin, presently available thermal data and derived products show many unexplained patterns, some of which probably were due to transient (and now untrackable) atmospheric events. Others, however, are believed to reveal real differences in the geologic materials, but current maps in general do not offer a sufficiently detailed base for correlation. Certainly some correlations are found with Landsat-mapped lithofacies, but more day-night pairs covering varying moisture cycles would have been necessary to see through such "noise" as windblown sand, surface-wind cooling patterns, and local moisture variations.

Linear features, often long reaches of streams that appear straight at HCMM resolution, are readily defined in the night images. Many of these coincide with breaks or trends in contoured aeromagnetic data, suggesting that basement tectonic elements have printed through the thick sedimentary sequence to control stream courses. This implies that during sedimentation at earlier times, such features effected some control of sedimentary depositional patterns a conclusion recently elaborated for the Powder River Basin (Slack, 1981).

The most remarkable, previously unrecognized, linear feature appears prominently on the night image of 5 and 27 September (figs. 4 and 15) and also 20 August (fig. 6). Although it is not recognizable as a discrete linear

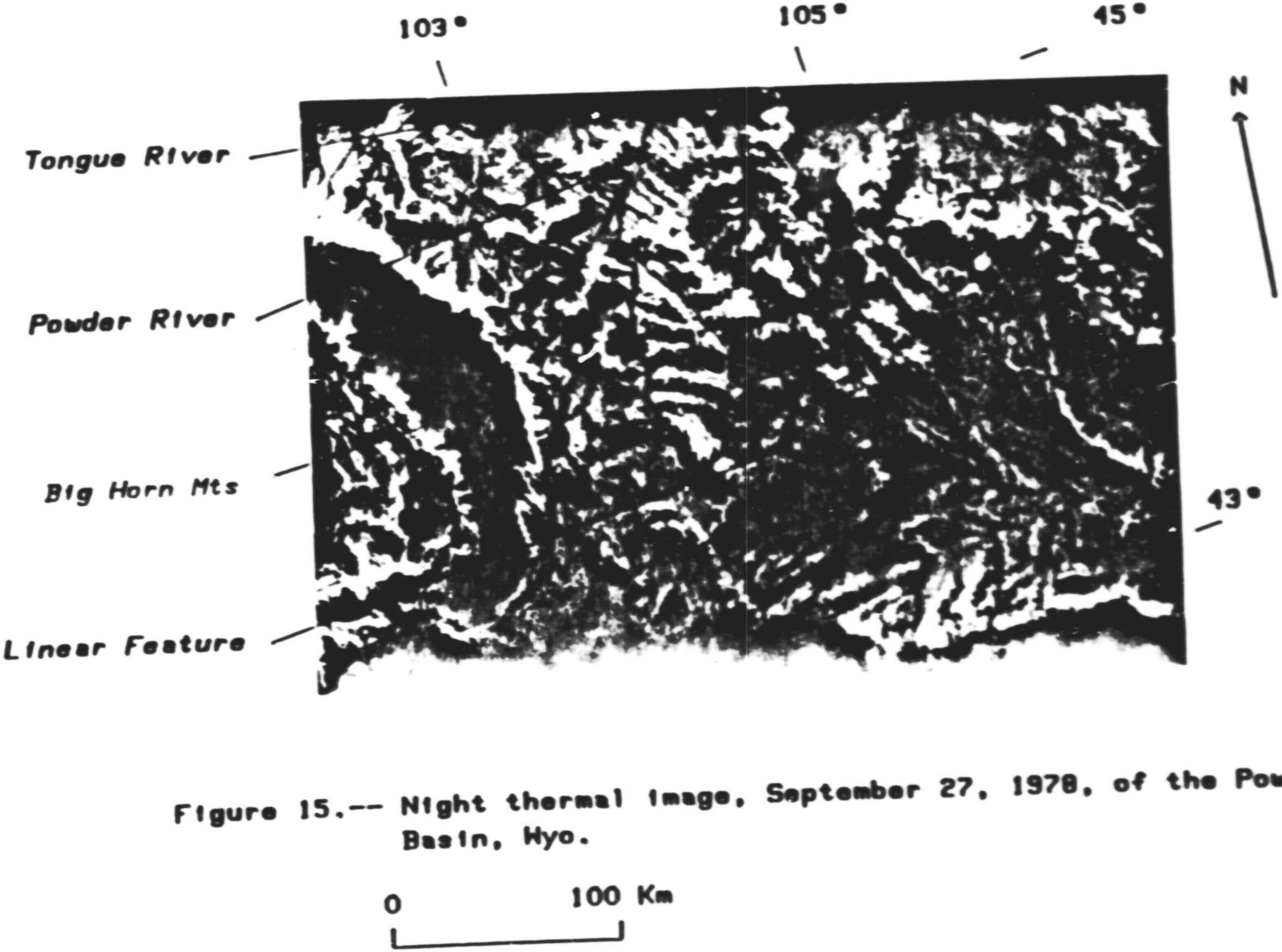


Figure 15.-- Night thermal image, September 27, 1978, of the Powder River Basin, Wyo.

feature on Landsat images (fig. 16a), topographic data (fig. 16b) show this lineament as a subtle drainage divide trending about N55°E. On the thermal images the southward-facing side is cooler by 3° or 4° C, and on the 20 August thermal-inertia image (fig. 7), the south side has a 17 percent lower thermal inertia (1215 TIU) than the north side (1460 TIU). Thus, the feature correlates with a subdued drainage divide but it cannot appear due to the slope effect and must represent - at least in part - a physical property difference across the divide. There is no explanation in existing geologic maps (at scales from 1:24,000 to 1:500,000) for this feature or why it separates temperature and topographic domains. The divide is parallel to the prevailing wind direction from the west-south-west as shown in eolian deposits south of the divide. Moreover, the divide also marks a change in direction of wind deposition; deposits to the north are laid down by winds from the north-northwest. It is possible that the relatively common eolian sand cover south of the divide has controlled drainage habit creating the distinctive topographic texture, and the sandy veneer might possibly cause the domain to have lower thermal inertia due to lower moisture retention. It is not likely, however, that the divide lineament itself is wind related. Extended to the northeast, it continues through the linear gap (of the same strike) between the Black Hills and the Bear Lodge Mountains. More important, it directly overlies one of the most significant breaks (fig. 17) in the aeromagnetic-map pattern (U.S. Dept. of Energy, 1979 a, b, and c) of the whole area, it is parallel to and roughly coincident with an inflection in the ground-water temperatures of the Madison Limestone (fig. 18), and its trend passes through several Tertiary intrusives (fig. 19) and possibly even through Lead, South

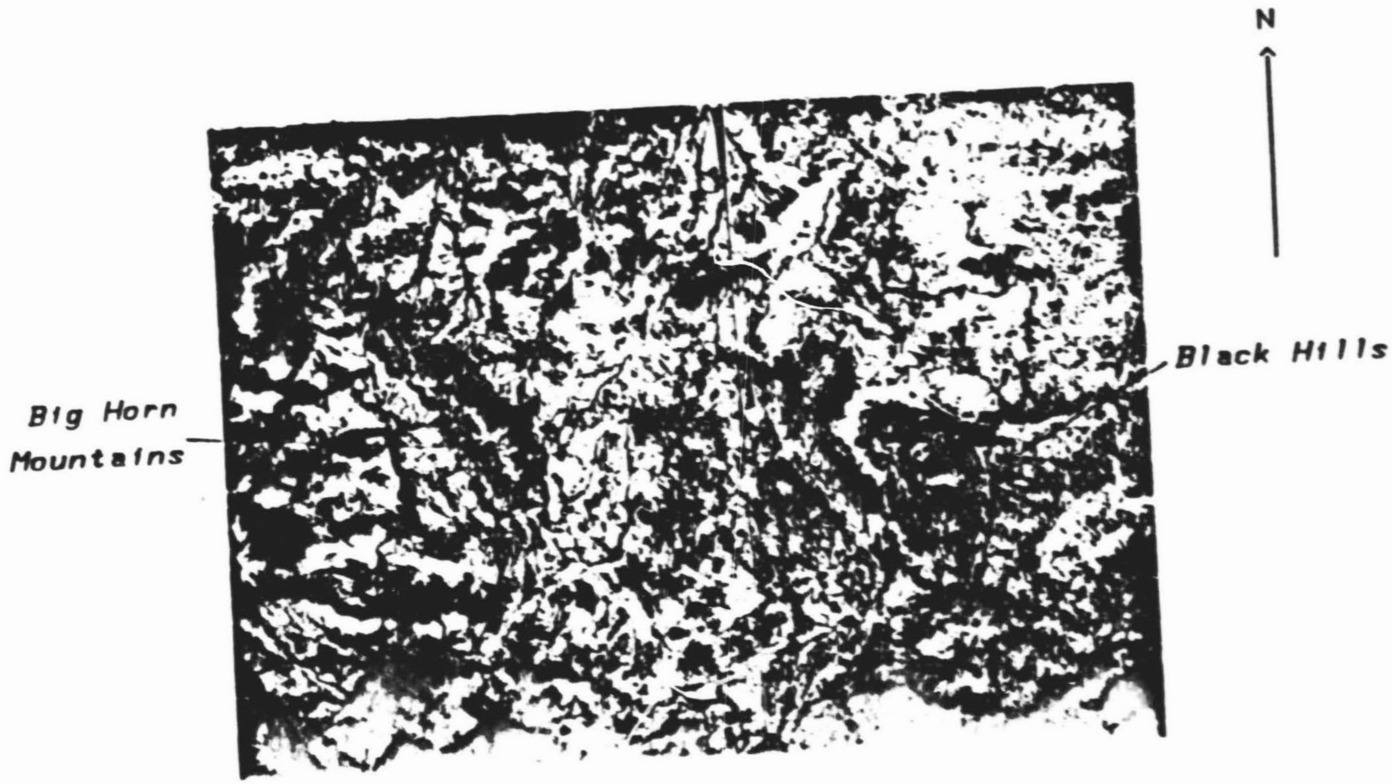


Figure 16a.-- Landsat (Band 5) image of the Powder River Basin Area, Wyo. A north-south mosaic line is present roughly 100 Km west of the Black Hills.

0 200 Km

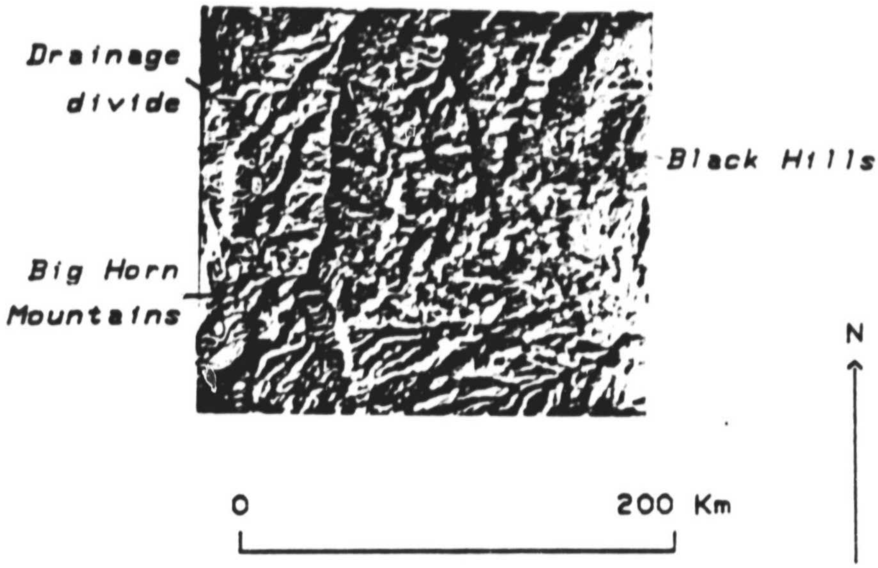


Figure 16b.--Illuminated topography image of the Powder River Basin, Wyo., showing the drainage divide which is coincident with the thermal lineament. The image was computed with a solar declination of -7.8 degrees and a local time of 0930 hrs.

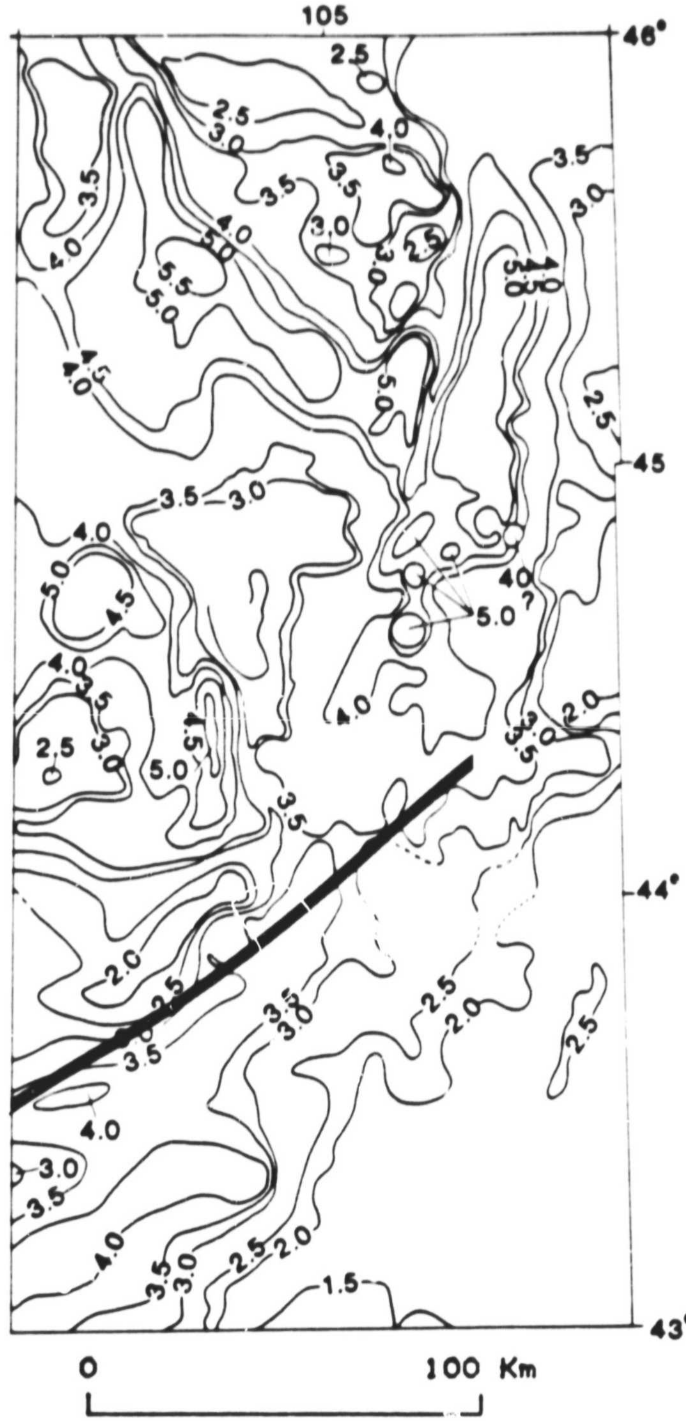


Figure 17.-- Total intensity magnetic field formline map, central Powder River Basin, Wyo. (U.S. Dept of Energy, 1979a-d). The heavy black line shows the position of the thermal lineament.

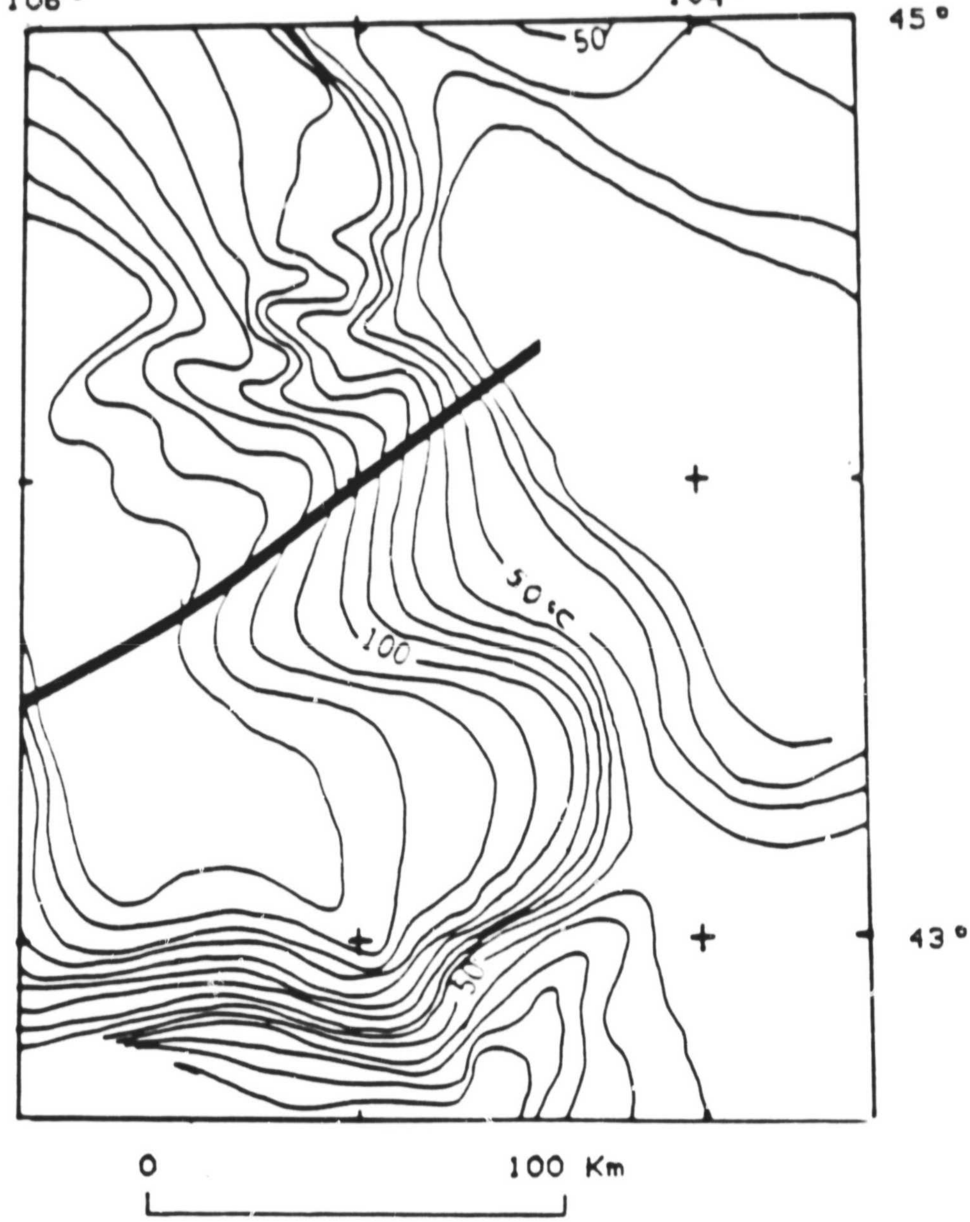


Figure 18.-- Ground water temperatures in the Madison Limestone and equivalent rocks (Head and others, 1978). Heavy black line indicates position of the thermal lineament.

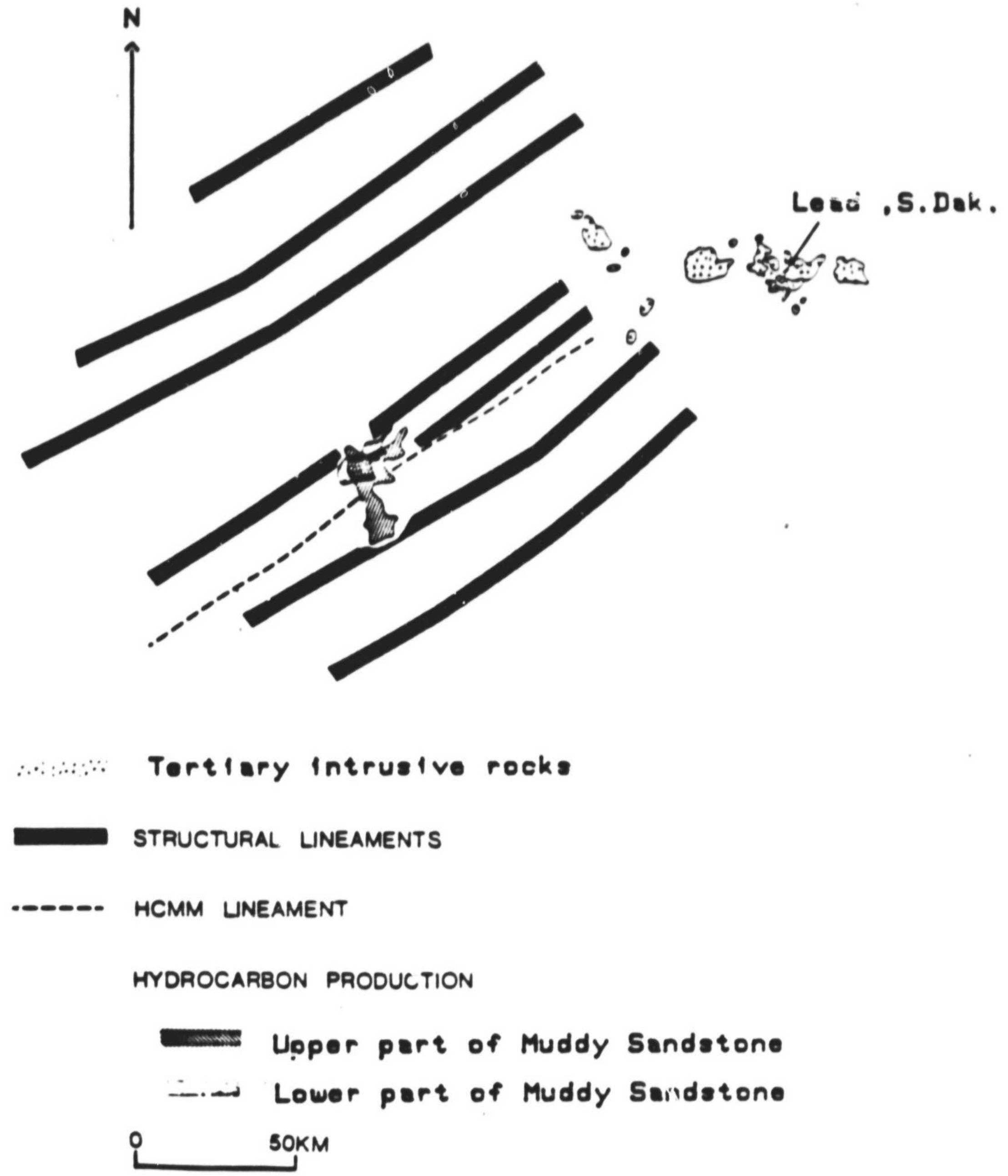


Figure 19.-- Location of the thermal lineament with respect to structural lineaments (Slack,1981) in the Powder River Basin, Wyo.

Dakota location of the Homestake Mine. In addition, stress measurements at Lead (Aggson and Hooker, 1980) imply that the preferred direction for normal faulting would be N50°E, virtually coincident with the orientation of the thermal lineament. Together these pieces of information provide permissive evidence for structural control relating to this feature. A recently published paper (Slack, 1981) presents substantial corroboration for the control. Using subsurface data, Slack proposes that a series of northeast-trending structural lineaments (fig. 19), which he calls the Belle Fourche Arch, have controlled sedimentation in this area and played an important role in determining hydrocarbon accumulation in the southern Powder River Basin. One of his lineaments, Gose Butte, is coincident with part of the thermal feature (fig. 19). Additional supportive evidence for structural control is reflected in the shape of the hydrocarbon producing horizons of the upper and lower parts of the Muddy Sandstone of Cretaceous age (fig. 19).

There is further corroborative satellite evidence for our explanation of the primary cause of the thermal lineament as a thermal-inertia contrast between dissimilar materials. The feature can be seen on two daytime Defense Meteorological Satellite Program (DMSP) thermal satellite images (near noon) and cannot be seen on a nighttime NOAA-5 thermal satellite image (near 9 pm). This latter image is acquired near the time when thermal data should largely be insensitive to thermal-inertia differences because it occurs near the crossing times of the diurnal curves.

We also examined USGS aircraft data across the lineament. Although we had not previously recognized the feature on these data, a very subtle thermal contrast could be observed in the vicinity of the lineament. Largely because of the slight temperature difference and the regional extent of the feature, it was not recognized on the aircraft data, and this result illustrates convincingly the potential power of regional thermal satellite data over aircraft data for structural-tectonic analysis.

A second, parallel lineament, not a stream divide but separating surface-textural domains, occurs 30 km to the south (figs. 4 and 15) and also overlies an obvious aeromagnetic break. These features appear to mark fundamental structural elements of the southern Powder River Basin and are newly recognized in HCMM data. To the north, parallel lineaments are marked in the images by the Belle Fourche and Little Missouri Rivers.

Information other than on geologic units per se can be gained from these images, most particularly in the demarcation of geomorphic (topographic-temperature) domains and in the discrimination of linear features. Night images are particularly useful in this regard. The 20 August 1978 image (fig. 6) provides very clear definition of major areas of distinctive topography, commonly linked with distinctive temperature patterns. The north and south halves of the basin are distinctly different; the areas east and northeast of the Black Hills differ from each other and from the domains of the basin. Other finer-scale units also are evident. These do not match the mapped geology and, like many geomorphic provinces, are products of a complex development history tied to more factors than the underlying bedrock. We believe that important information can be gained in this aspect of the HCMM images, especially in understanding surface processes during Tertiary and later time. Such information also may lead an understanding of near-surface groundwater hydrology across large, diverse areas. We have examined the domains from the points of view of mapped geology, ground-water chemistry, mineral and hydrocarbon resources, and tectonic framework, and correspondences are not readily apparent. This is an aspect of the mission data that we did not originally anticipate. However, Schneider and others (1979) showed that the NOAA (National Oceanic and Aeronautics Administration) satellite VHRR (Very High Resolution Radiometer) data with 900-m resolution permitted the defining of geomorphic domains very clearly. This work and our present observations suggest that careful consideration of satellite thermal image data by geomorphologists and hydrologists should be undertaken.

2.3.2 Application to resource studies

2.3.2.1 Oil and gas

It was hypothesized that a few oil and gas fields of the Powder River Basin had enough leakage of gas, probably mostly CO_2, that calcite cementation would have occurred near the surface to make the bedrock more resistant, possibly to form local topographic highs. A few fields do indeed underlie local topographic highs, but this could be fortuitous, and no evidence of leakage and cementation has been cited in the literature. However, a reconnaissance survey of soil-gas helium shows 37 significant helium anomalies within the Wyoming portion of the basin (fig. 20), where most of the oil and gas occurs. The reconnaissance scale of helium sampling does not permit an accurate comparison with individual occurrences of oil and gas except for the largest fields, but it can be said that all but five of the helium anomalies occur over oil and gas fields, and those five are near producing fields. Many

Figure 20.-- Location of helium anomalies, uranium fields, and oil-gas fields in the Powder River Basin, Wyo.

oil and gas fields do not have overlying helium anomalies, and the implication is considered to be that some fields leak gases upward and many more do not. Perhaps 15-20 percent of oil or gas fields might be considered to have leaked helium, although that number might easily prove twice as large if more detailed sampling were done. The percentage of fields where gases may have produced cementation, especially enough to cause detectable changes in surface-temperature character, clearly would be expected to be small. Thus, it is encouraging to note that visual discrimination suggests thermal-inertia anomalies (20 August image, fig. 7) for 9 out of the 37 areas with anomalous helium values (fig. 20). These areas have consistently and noticeably higher values than the surrounding areas, in keeping with expectations if cementation is locally increased. Most of the areas do not have noticeably different topography than their surroundings. Two of the helium-thermal-inertia areas do not overlie known oil or gas fields but both are surrounded by fields and have several dry holes within the areas. The dry holes may have had only subeconomic shows of oil or gas, in which case leakage to the surface may still have occurred; or perhaps holes simply have not been drilled in the right places. The two areally largest helium anomalies, one over a giant gas field and the other in one over the "barren" areas just described, are marked by fairly distinct oval rings in the thermal-inertia pattern.

Helium anomalies are numerous and areally large in the Montana portion of the basin. They occur in a roughly defined ring which corresponds to the perimeter of a roughly circular area of distinctive topography 75 km wide and approximately bisected by the Powder River. This area is virtually without oil-gas production and few wells are shown on available source maps. But the helium anomalies correspond to the ring of very warm areas seen in the night 20 August image. We know of no reason to expect such helium anomalies in this region except in association with oil and gas, and the warm areas are mostly areas of outcrop, perhaps where cementation is increased. Information has not yet been found on facies in the subsurface rocks that might contain oil and gas. If the facies are not truly favorable, uneconomic amounts of oil and gas might have been present and leakage could have occurred. If the facies are favorable, the area deserves a closer look for exploration.

An additional point of interest is the possible relationship of HCMM lineaments and oil-gas occurrence. The major thermal lineaments transecting the southern part of the basin (fig. 21) define a block that contains most of the significant helium anomalies. Trends in the helium anomalies as contoured from present data commonly parallel HCMM lineaments. The two largest fields, Fiddler Creek and Clareton, are long and narrow and parallel in trend (and between) the basin-transecting thermal lineaments. The west end of the Clareton field ends in a prominent fork, with the southern one of the main lineaments passing through the fork junction.

2.3.2.2 Uranium

The uranium districts of the Powder River Basin (fig. 20) have local areas of surface alteration as large as 5 by 7 km. These, however, are exposed discontinuously, and differ only slightly in lithologic character and thermal properties relative to the surrounding unaltered ground. If the bedrock were totally exposed, an increase in thermal inertia of perhaps 10 percent might make the altered ground detectable. In any case, the only

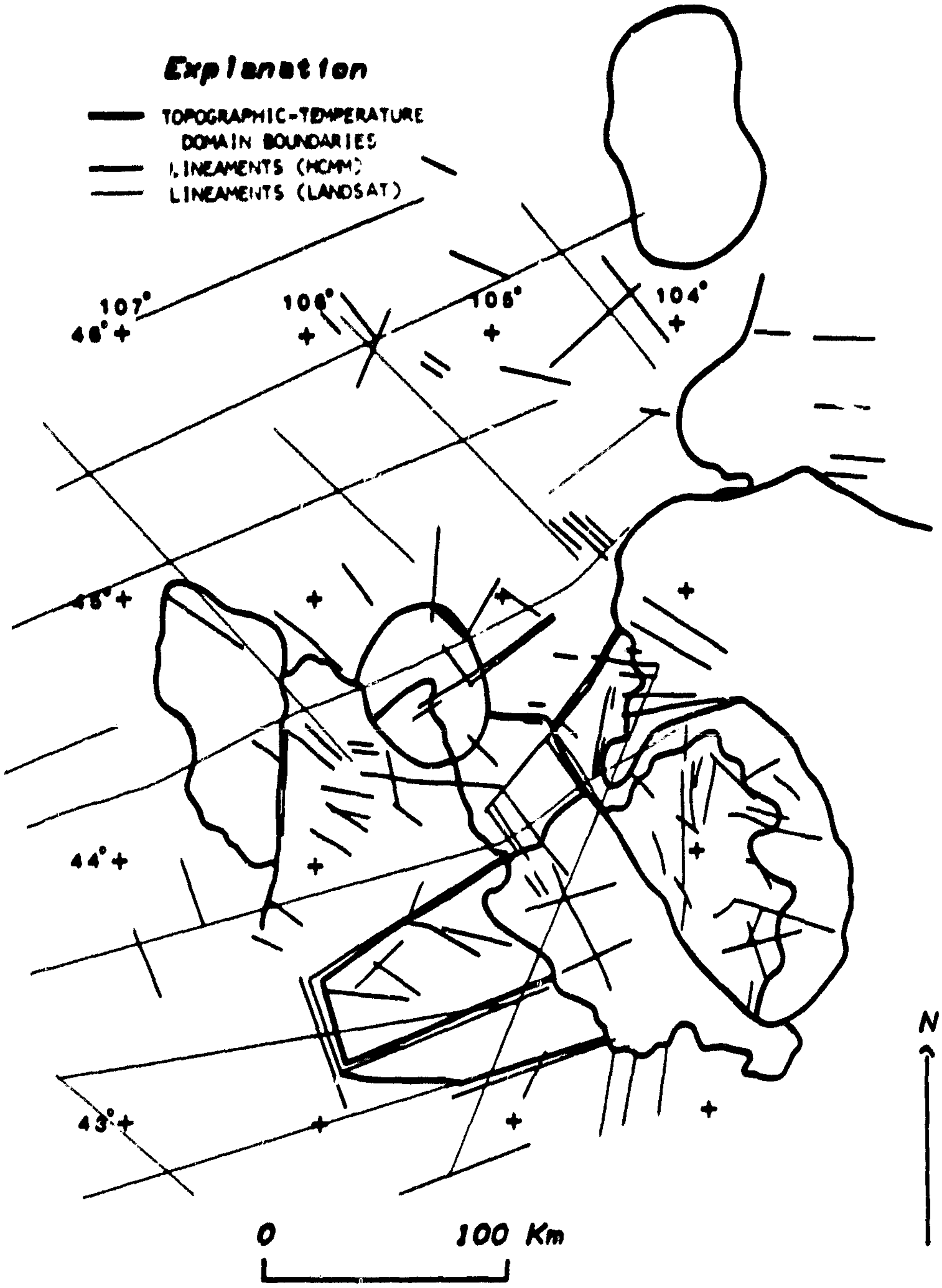


Figure 21.-- Major thermal and Landsat (Marrs and Raines,1981) lineaments transecting the southern part of the Powder River Basin, Wyo. and boundaries of the topographic-temperature domains.

thermal-inertia data set does not cover the main uranium areas; the 20 August data end east of the districts or have clouds over the fringe areas where uranium ground occurs. We have examined low-altitude aircraft thermal data for the altered ground, and so far "noise" (soil cover, windblown sand, local topography, and moisture variations) seems to completely overwhelm "signal" related to the discrimination problem.

2.3.2.3 Geothermal flux

Another aspect of our study is to examine the utility of HCMM data for geothermal flux mapping. We found that the underground coal fires now burning north of Sheridan, Wyo., are detectable (barely) on nighttime HCMM thermal images. Comparison with a mosaic of aircraft thermal images of this area (fig. 22) illustrates the scale effects on the appearance of small geothermal anomalies. On the aircraft data the anomalies have a sharp, clearly defined pattern, whereas the satellite data show an indistinct pattern which is not distinguishable from geologic and topographic effects. Also, the satellite appearance of drainage features is distinctly different from the aircraft data. From nighttime aircraft data, the Tongue River appears as a sharp warm anomaly with cooler surroundings. The satellite image, because of its coarser resolution, does not discriminate the narrow water channel, and, thus, the drainage appears entirely as a cool zone.

To examine the expression of geothermal anomalies more fully, HCMM scenes of Yellowstone National Park were analyzed. The region has a classic expression of most of the typical hydrothermal features of a vapor-dominated system. A careful comparison between a nighttime image (fig. 23a) and a detailed

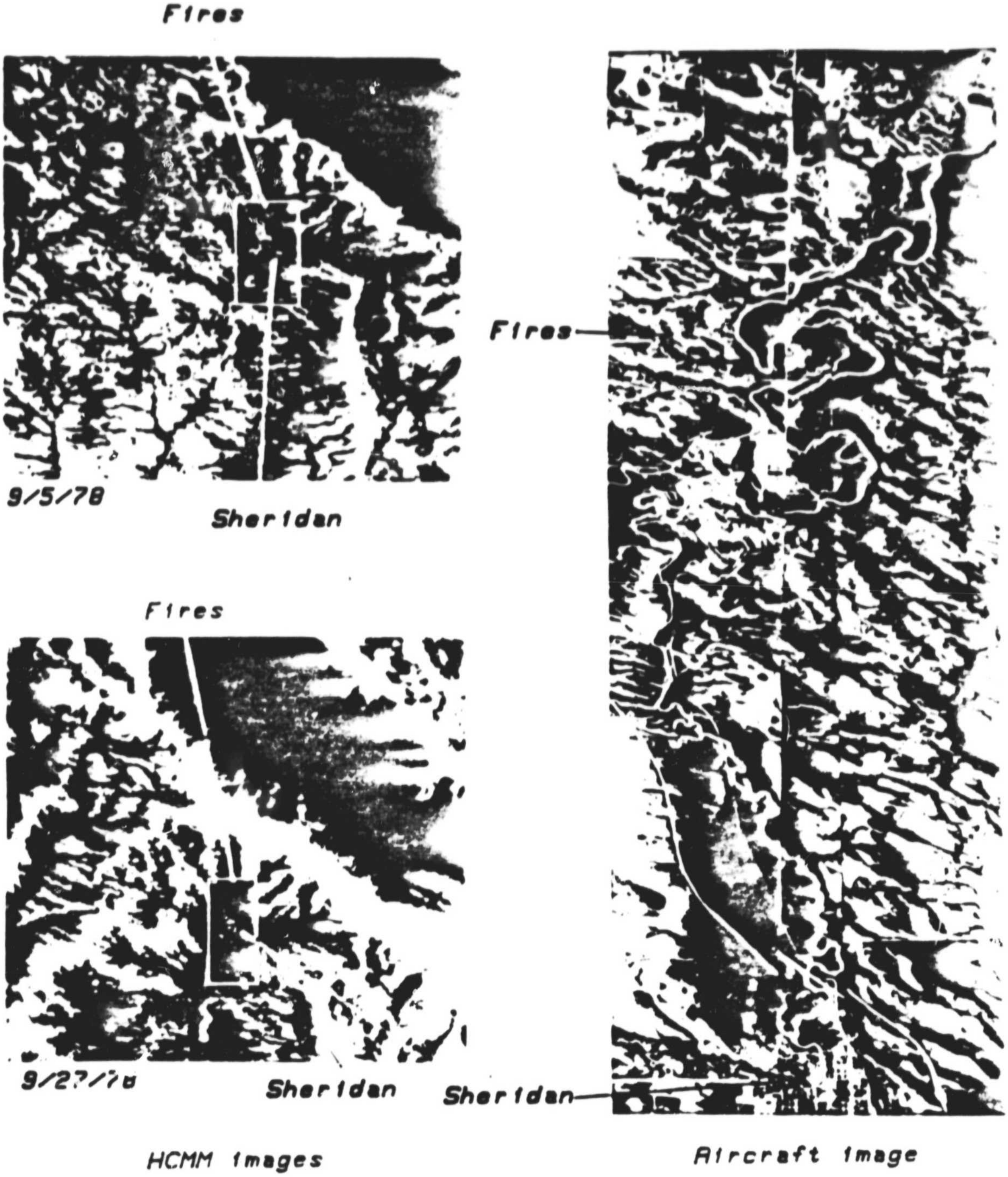


Figure 22.-- Areas of underground coal fires near Sheridan, Wyo., as seen on HCMM and aircraft thermal data.

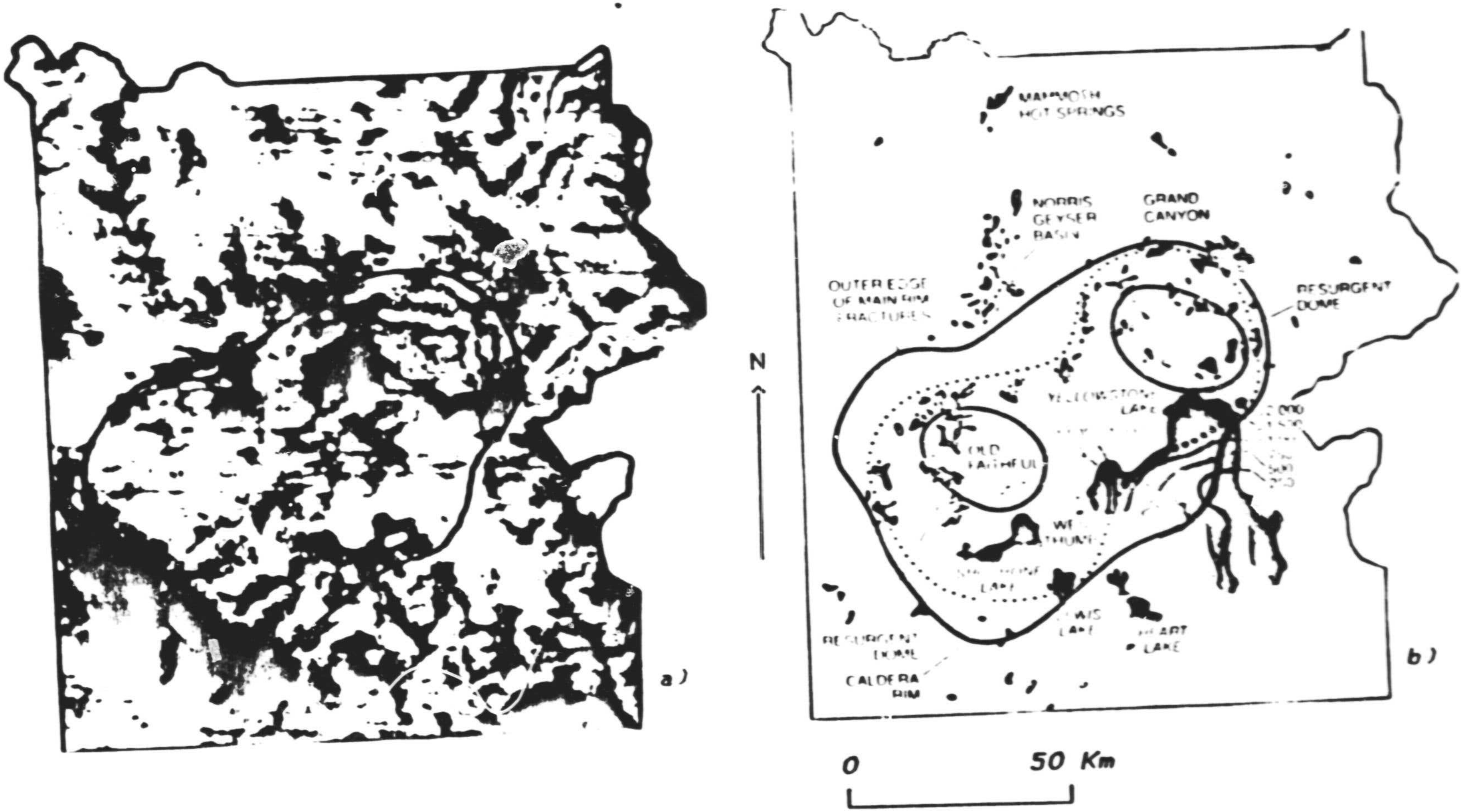


Figure 23a.-- Nighttime thermal image of Yellowstone National Park with caldera outline superimposed.

Figure 23b.-- Location of hydrothermal features (Smith and Christiansen, 1980).

map of the hydrothermal features (Smith and Christiansen, 1980) (fig. 23b) was made using a zoom transfer scope. The hydrothermal features commonly were not expressed as warm anomalies (fig. 24a), and most of the warm anomalies on the images are not hydrothermal-associated features (fig. 24b). These results demonstrate that nighttime satellite images at this scale are unlikely to be useful for detecting similar features elsewhere. Of greater geologic interest was the correlation between the caldera outline, some thermal anomaly lows, and in particular the anomaly bounded by a sharp edge (fig. 23a) which coincides with that part of the gravity field map outlining the southwest side of the caldera (fig. 25b). Although this latter anomaly is a feature with no direct counterpart in Landsat images (fig. 25a), it may provide additional information on the volcanic-tectonic setting. From these brief observations we conclude that the HCMM data can be useful in understanding the regional structural setting of geothermal fields but are not likely to be useful for mapping hydrothermal features.

2.3.2.4 Mapping geologic units in an arid desert environment

The Cabeza Prieta area in Arizona is an arid desert environment with geologic units exposed at a scale suitable for discrimination in HCMM satellite images. The area lies very near the major copper district at Ajo and contains old prospect developments in hydrothermally altered ground. No detailed geologic mapping has been previously done of this area as it contains a proposed Wilderness site. The main objective of our investigation has been to extend the interpretation techniques developed in our Powder River Basin study.

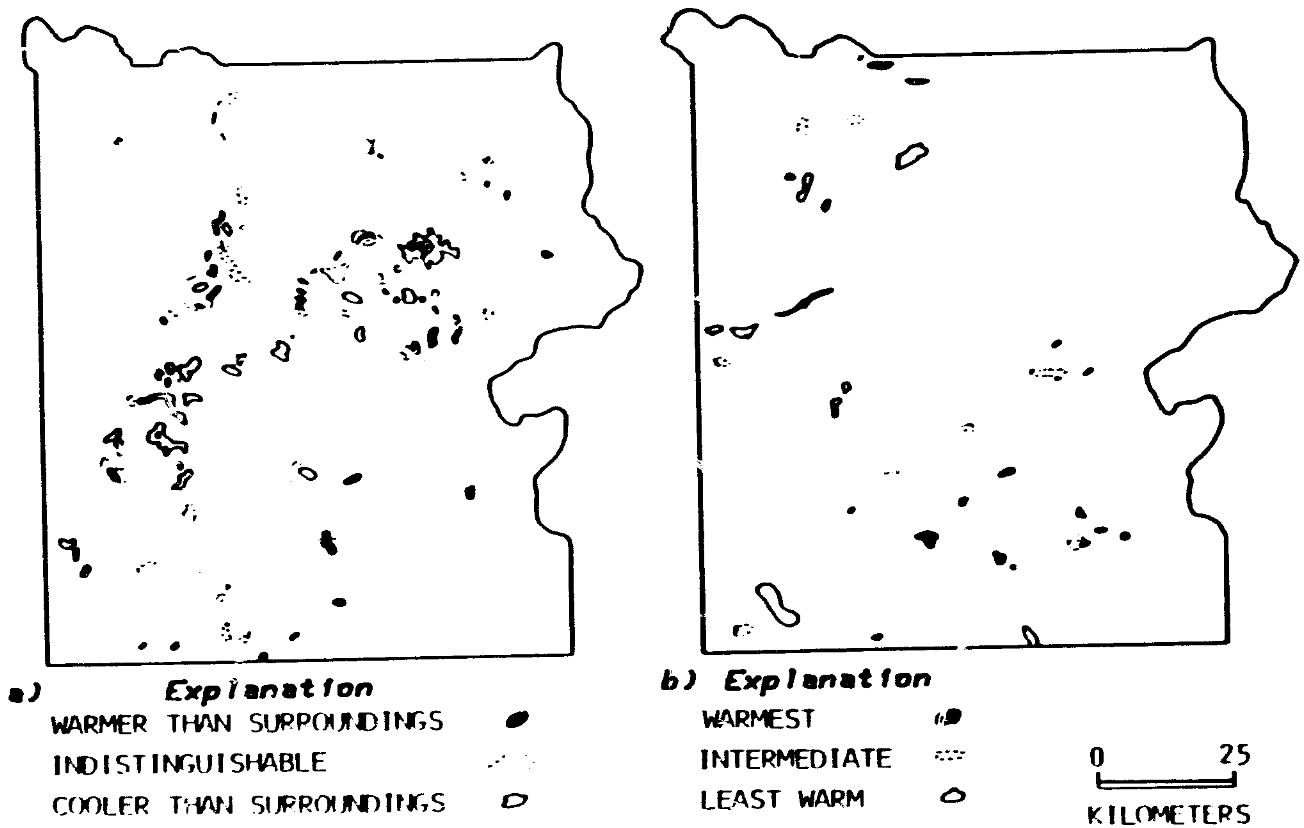
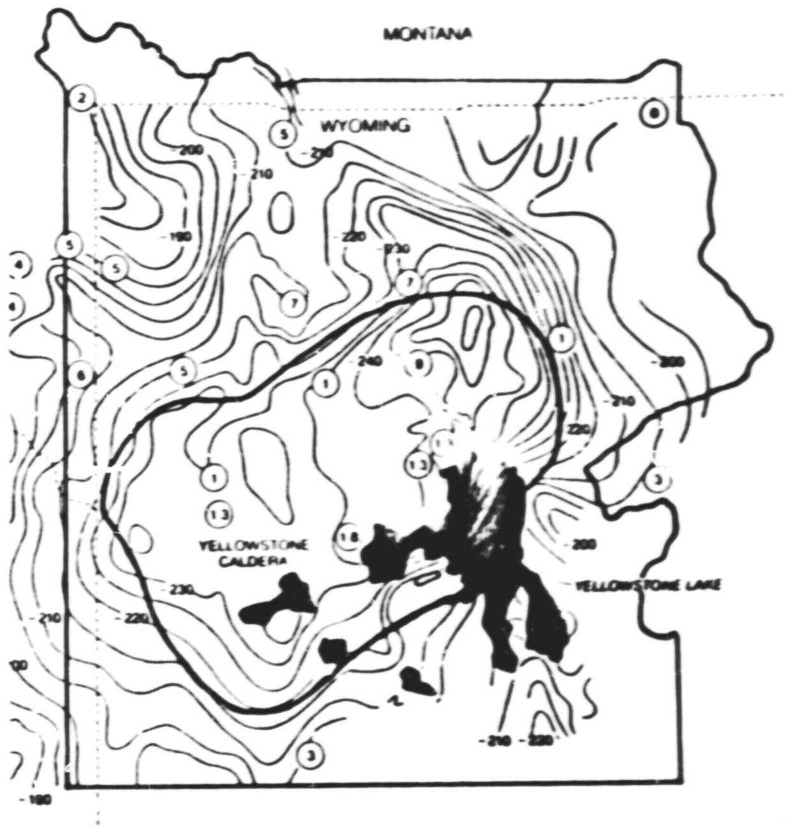


Figure 24a.— Nighttime temperatures of known hydrothermal features.

Figure 24b.— Ranking of thermal night anomalies.

a)



b)

0 50 Km

Figure 25a.-- Landsat image of Yellowstone National Park with the caldera and park boundaries outlined.

Figure 25b.-- Gravity field contours (Smith and Christiansen, 1980).

A thermal-inertia image (fig. 26) was constructed using the April 3 and 4, 1979 scenes (AA0342-09150-3; AA0343-20230-1, 2) with 36-h separation between the day and night acquisition times. The image was then compared to the Ajo geologic map (Kahle and others, compilers, 1978) and an estimate was made of the thermal-inertia values of various geologic materials (table 1). Among the sedimentary deposit materials, a wide range of thermal-inertia values was found. From highest to lowest values these included a wet coal-mine dump near Ajo (1890 TIU), active pediment areas (1360 TIU), stablilized dunes (1065-1300 TIU), and active dunes (830-1065 TIU). The most probable explanation for this ranking is due to the strong effect of moisture content on thermal inertia. Generally, active dunes should have the lowest thermal inertia, as observed, owing to their low density and low capacity to retain moisture.

A somewhat surprising result was that the thermal inertias of the various igneous rock units were measurably different, indicating a finer discrimination capability than previous laboratory data in the literature would suggest (Watson, 1979, 1981a). The literature values of thermal-inertias of igneous rocks show no correlation with either composition or grain size and are indistinguishable from each other. In Cabeza Prieta, however, we found that the felsic intrusives (together with gneiss and schist) had the highest thermal inertias (>2200 TIU), that extrusive rocks of mafic composition had intermediate thermal inertias (approximately 2000 TIU) and that extrusive rocks of less mafic composition had the lowest thermal inertia (<1900 TIU). We believe that the felsic intrusives have the highest thermal inertias because of their high quartz content and high surface density and that the differences among extrusive rocks occur because of density differences associated with the amount of

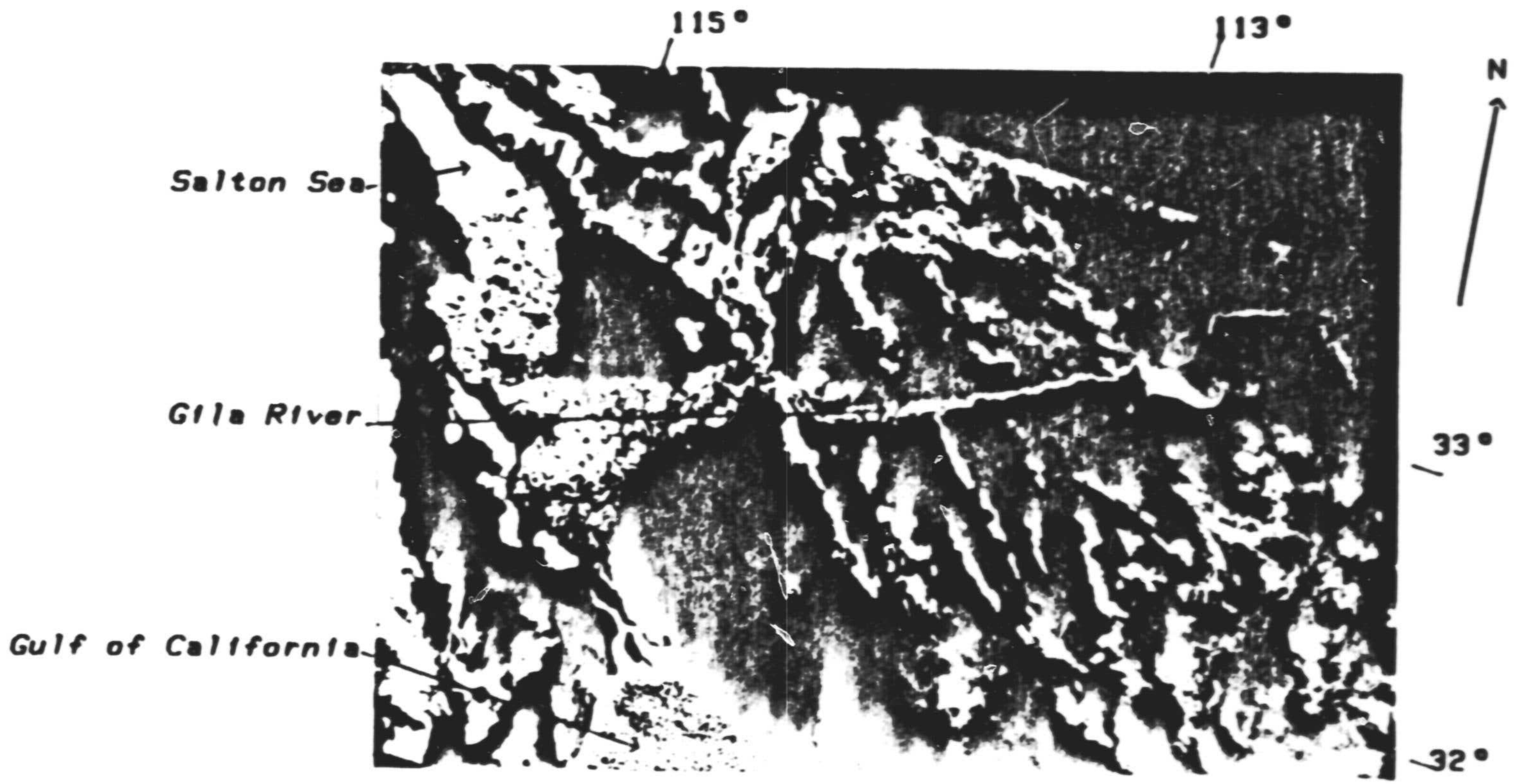


Figure 26.-- Thermal-inertia image, April 3/4, 1979 of Cabeza Prieta, Ariz.

0 100 Km

Table 1.--Estimates of thermal inertia of various geologic materials

Geologic Material	Thermal Inertia (TIU)	
	mean	range
Active Dunes	945	(830-1065)
Partially stabilized dunes	1240	
Cluster dunes	1180	(1065-1300)
Active pediment slope	1360	(1300-1475)
Wet mine dump (Ajo)	1890	
Granite, gneiss, schist	2200	(1975-2525)
Mixed intermediate to mafic volcanic rocks	1750	(1550-1950)
Basalt	1950	(1700-2200)

volatiles present during their formation and their mafic content. Although these values are suggestive of the possibility of discriminating among the various units, the large overlap in the range of values (histograms) indicates that classification based solely on thermal inertia differences may not be feasible. The overlap between the units can be attributed to several causes. These units are exposed in the most rugged terrain of the region and thus topographic effects are most pronounced in these parts of the image. The ground that is "sensed" by the technique is a weighted average over the diurnal thermal wavelength (approximately 1 m), with the primary contribution coming from the rock and rock fragments of the upper decimeter. Thus differences in the effects of weathering processes on the various rock types in this environment can produce some degree of thermal-inertia differences.

Because the Powder River Basin was relatively flat terrain the topographic effects were not sufficiently important to be considered. In the Cabeza Prieta area, however, slopes in excess of 20° can be found. To examine the contribution of topography, the thermal inertia measured from remote observations we considered the aspects of elevation and slope separately. The elevation factor due to changes in the solar and sky radiation, has been examined and used to predict the equivalent change in the effective thermal inertia (i.e., that derived from remote rather than in situ measurement) as a function of elevation (Hummer-Miller, 1981b). The effective thermal-inertia gradient under clear-sky conditions should be roughly 100 TIU per kilometer. In Cabeza Prieta, where the maximum relief is 700 m, this maximum correction is only 70 TIU and the factor is additive for increasing elevation (i.e., rocks at higher elevations will appear in the image to have lower thermal inertias).

The slope factor was evaluated by using an algorithm recently developed (Watson, 1981b). The turn has an azimuthal variation proportional to $\cos(\phi - 37.6^{\circ})$ where ϕ is the direction of slope measured counterclockwise from north, and thus ridges with an axial orientation of roughly N40°W will display a minimal topographic effect. The most consistent topographic grain in the Cabeza Prieta area is northwest-southeast and thus generally satisfies this constraint. The correction can amount to several hundred TIU's for slopes in excess of ten degrees and orientations orthogonal to N40°W (i.e., N50°E).

The primary intent of this study area was to examine correlations between thermal-inertia values and a variety of common rock types exposed in an arid area. In the process of this analysis we also observed, on the night thermal image, a number of linear features associated with known major faults (San Andreas fault, Garlock fault) and the absence of lineaments in an area near Gila Bend which is noted for the absence of structural features (Gila gap). We also were able to determine a measure of the satellite's spatial frequency response (and thus its ability to detect high-contrast linear features) by the observation that Interstate-10 from Gila Bend to Yuma was observable.

3.0 MODEL DEVELOPMENT

Several advances have been made in the development of techniques to analyze thermal-infrared data. An algorithm to determine the sensible-heat flux from simple field measurements (wind speed, air and ground temperatures) has been developed. It provides a direct solution, in parametric form, that can be displayed graphically or tabularly. This method has an advantage over the previous iterative solution in that the computation is both very fast and it also provides a clearer understanding of the drag coefficient, with its variation and response to different conditions. At low wind speeds the drag coefficient cannot be treated as a constant. Both the computational speed and analysis of the drag coefficient can be important for remote-sensing applications involving thermal scanner data (Watson, 1980).

A substantial advance was the development of a method, based solely on remote-sensing data, to estimate those meteorological effects which must be known for thermal-inertia mapping. It assumes that the atmospheric fluxes are spatially invariant and that the solar, sky, and sensible heat fluxes can be approximated by a simple mathematical form. Coefficients are determined from a least-squares method by fitting observational data to our thermal model. A comparison between field measurements and the model-derived flux shows that good agreement can be achieved. An analysis of the limitations of the method was also made (Watson and Hummer-Miller, 1981a).

This new method of estimating atmospheric parameters was the basis for a revised thermal-inertia algorithm (Watson, 1981a). The new form is:

$$P_{ij} = (\overline{P} \cdot \Delta\overline{V} + C(\lambda,\delta) \quad (\overline{A}-A_{ij}))/\Delta V_{ij}$$

where A_{ij} and ΔV_{ij} are the corresponding albedo and temperature difference of the ith pixel and jth line. $\overline{A}$ and $\overline{V}$ are the mean values for the area in question, and $\overline{P}$ is a select value for the mean thermal inertia (generally 1500 TIU). $C(\lambda,\delta)$ is a function of the site latitude, λ, and the solar declination, δ. The advantage of this algorithm lies in the fact that we are dealing with albedo and thermal differences rather than absolute values. Thus, the computed thermal inertia is less sensitive to offsets caused by calibration errors or atmospheric backscattering and transmission effects.

Other modeling studies centered around developing an algorithm for elevation correction of temperature and thermal-inertia images (Hummer-Miller, 1981b). They are based on application of the linearized Fourier series method (Watson, 1975; Watson, 1979) to simple forms of the solar flux (Hummer-Miller, 1981a) derived from a representative set of field observations. It was found that flux variations with elevation can cause changes in the mean diurnal temperature gradient from -4° to -14° C per km (evaluated at 2000 m). Changes in the temperature-difference gradient of 1°-2° per km are also produced and these are equivalent to an effective thermal-inertia gradient of 100 TIU per km.

In addition, a simple topographic slope correction method has been developed using the linearized thermal model and assuming slopes less than about 20°. The correction can be used to analyze individual thermal images or composite products such as temperature difference or thermal inertia. Simple curves were determined for latitudes of 30° and 50° (Watson, 1981b). The form is easily adapted for analysis of HCMM images using the DMA (Defense Mapping Agency) digital terrain data (Watson, 1981b).

A major concern in this investigation has been the accurate registration of day and night images. We have developed an image-registration algorithm which appears to be substantially better than the current registration products provided by NASA (Watson and others, 1981). The initial test of this algorithm used the 20 August 1978 data of the Powder River Basin. A small number, less than ten, of very clearly delineated features, generally the water-dam interfaces of reservoirs, were selected as control. Subsequently, an affine transformation was determined by best fitting these points. Our first test indicates a residual error of < 2 pixels. The NASA product for the same scene displays errors of many pixels resulting in "double drainage" effects and an offset of several kilometers.

During the initial stages of our experimentation with control points, we expected that the drainage pattern in the Powder River Basin was substantial enough to provide extensive control for registration. We discovered, however, that drainages are often unreliable identification features and the resulting control points were too inaccurate to provide the transformation coordinates. We also experimented with cross-correlation techniques in the Cabeza Prieta area but were unsuccessful owing to the strong topographic grain. The affine transformation which we employed has the additional advantage that it can be adapted to very fast computer processing schemes (Braccini and Marino, 1980).

4.0 DIGITAL IMAGE PROCESSING

This section presents an outline of the image processing techniques used in this study. Figure 27 is a simplified flow diagram of the basic processing steps; the computer programs referenced in this diagram are included in Appendix A. The initial processing involves obtaining the HCMM computer-compatible tapes (CCT) and altering the data format to be consistent with our computer software. Sometimes the area of interest spans two scenes and, consequently, must be appended into a single file. To produce enhanced images of these products, the appropriate area of the image is statistically sampled to form a histogram and to derive the mean, median, mode, variance, standard

IMAGE PROCESSING

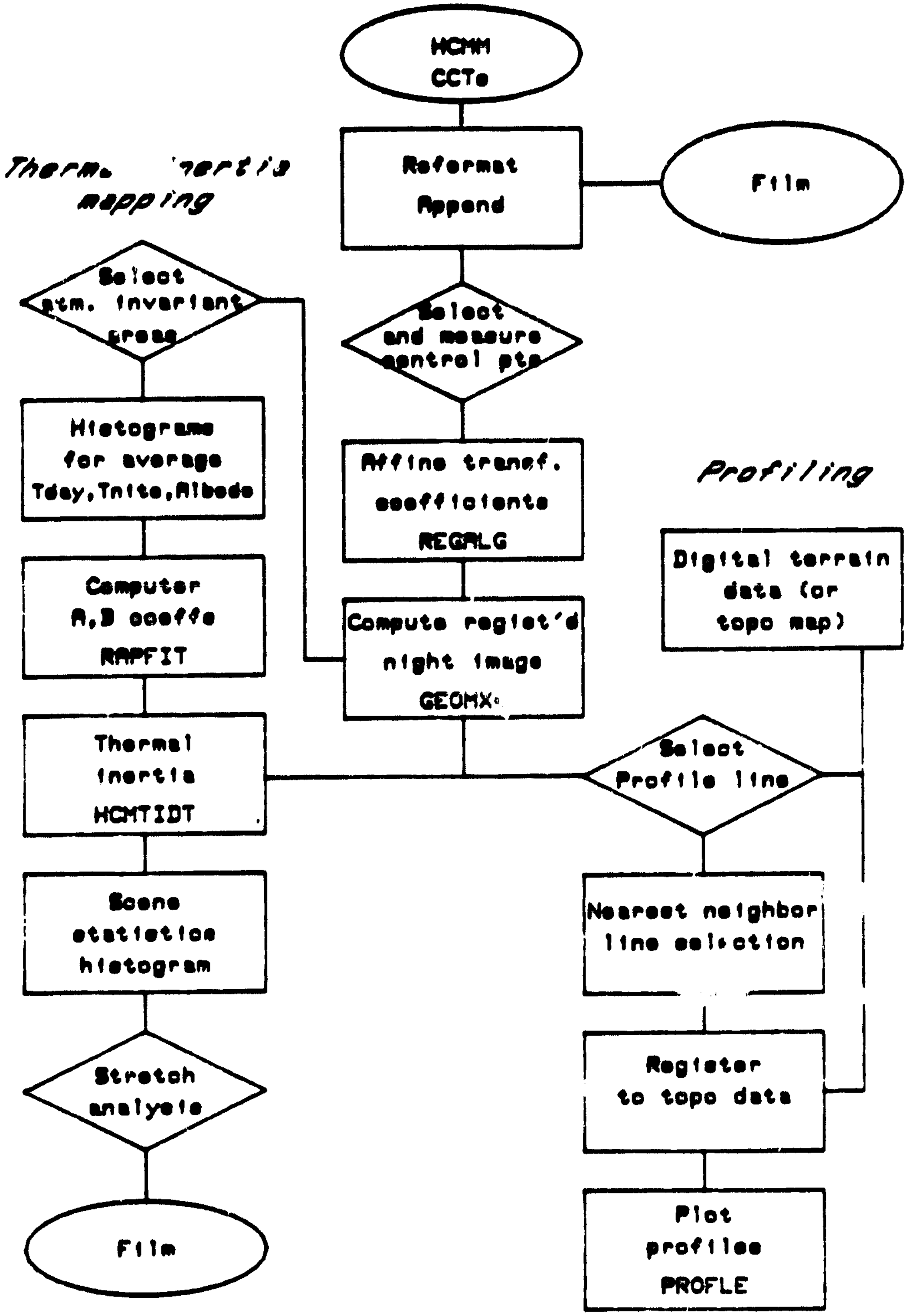


Figure 27.-- Flow chart of the image processing procedure.

deviation, and cumulative frequencies. With these statistics a decision is made as to how the scene contrast should be enhanced using an appropriate transformation of the scene brightness. From our experience a 1 or at most 2 percent linear stretch of the data produces a good starting point. Thus the 1 or 2 percent and 98 or 99 percent points are transformed linearly to the extremes of a 256-step gray scale (0 and 255) and the center density value (Dn) of the distribution is transformed linearly to the center of the gray scale (127 Dn). Other useful products include linear stretches on paper where a single print character is assigned for each Dn value and color-coding on film.

The next processing operation is performed to register the night-thermal file to the day files. This operation, including a discussion of the general considerations, are detailed in Watson and others (1981). Control features are selected from the positive transparency images produced from the CCT and locations are measured to one pixel accuracy. These values are then used to determine the affine coefficients for a best-fit transformation (REGALG). This transformation provides a rotation correction for the inclined satellite orbital tracks, an origin shift, and scale changes both along and across the scan line. The actual registration of the night file is then performed using the affine transformation coefficients in the GEOMX4 computer program. This program assigns radiometric values to the newly registered image employing a nearest-neighbor method.

At this stage the data are in the appropriate format for thermal-inertia and temperature-difference mapping. The algorithms which we use (Watson, 1981a) employ average scene values of albedo, day temperature, and night temperature. The portion of the scene from which these values are determined is based on the assumption of atmospheric invariance and thus, as a minimum constraint must be cloud-free on both images. The program RAPFIT is then used to compute the appropriate coefficients for this algorithm, and the program HCMTIDT is employed to construct both temperature-difference and thermal inertia files. The resulting files are then processed using these techniques described in the beginning paragraph of 4.0.

Another analysis technique used in this study is to construct profiles across the image data. The end points of particular profiles are chosen and digital values along the line are obtained for all products: day reflectance, day thermal, registered night thermal, and thermal inertia using a nearest-neighbor algorithm. The corresponding elevation profile is obtained by digitizing the appropriate portion of a 1:250,000 topographic map and adjusting it to match the satellite data. This task is made easier if the profiles cross distinct features such as reservoirs and rivers. After the elevation data are registered to the satellite data, the program PROFLE is used to plot the profiles and cross plot pairs of data values. The profiles can be plotted at various scales and thus directly overlaid on any base material for comparison. The cross-plotting option is valuable for examining correlations (for example, we observed that the day thermal versus elevation data fit the adiabatic lapse rate).

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5.1 APPENDIXES

Listings of the following computer programs described in section 4.0 follow:

REGALG

RAPFIT

GEOMX4

HCMTIDT

PROFLE

```
10     ! REGALG   To compute best fit affine transformation for HCMM regist.
20     ! Program language is extended Basic.
30     ! Program written by K.Watson
40     OPTION BASE 1
50     STANDARD
60     INTEGER I,Printer
70     DIM Xold(100),Yold(100),Xnew(100),Ynew(100),Name$[50],S(3),R(3),Xt(100),Yt(100),G$[80],Coun
(100),Pal(4),Lxl(4)
80     PRINTER IS 16
90     LINPUT "Do you wish to read an input file Y or enter values manually N",Anz$
100    IF Anz$="Y" THEN GOTO 130
110    LINPUT "Do you wish to store an input file Y or N",Any$
120    IF Any$="N" THEN GOTO 350
130    LINPUT "Enter Filename for Day(new) points",File1$
140    IF Any$="Y" THEN CREATE File1$,10
150    LINPUT "Enter Filename for Nite(old) points",File2$
160    IF Any$="Y" THEN CREATE File2$,10
170    IF Any$="Y" THEN GOTO 350
180    ASSIGN #1 TO File1$
190    READ #1;N
200    Nnum=N
210    REDIM Counter(N)
220    READ #1;G$     ! Implies a title which is ignored
230    FOR I=1 TO N
240    READ #1;Ynew(I),Xnew(I)
250    Counter(I)=I
260    NEXT I
270    ASSIGN #1 TO File1$
280    ASSIGN #1 TO File2$
290    READ #1;Jmax
300    READ #1;G$     ! Ignored title
310    FOR I=1 TO N
320    READ #1;Yold(I),Xold(I)
330    NEXT I
340    GOTO 530
350    INPUT "Enter number of control point quadruples",N
360 REDIM Xold(N),Yold(N),Xnew(N),Ynew(N),Xt(N),Yt(N),Counter(N)
370    Printer=16
380    PRINTER IS Printer      ! For debugging
390    LINPUT "Enter a descriptive name <50 char for this registration",Name$
400     INPUT "Enter the maximum lines and pixels from old image",Lmax,Pmax
410    PRINT PAGE
420    PRINT LIN(10),SPA(5),"To enter control points use the format:"
430    PRINT "    Day(new)                        Night(old)"
440    PRINT " scan no,pixel no      ,       scan no,pixel no"
450    FOR I=1 TO N
460    ! NOTE:Scan=Line
470    PRINT LIN(9),SPA(20),"Control point:";VAL$(I)
480    INPUT "Scan_new,Pixel_new,Scan_old,Pixel_old",Ynew(I),Xnew(I),Yold(I),Xold(I)
490    Counter(I)=I
500    PRINT PAGE
510    NEXT I
520 Enter:  PRINTER IS 16
530    PRINT PAGE
540    PRINT LIN(10),SPA(15)," DATA CHECK"
550    PRINT "Control no        NEw                    OLD"
560    PRINT "              Line        Pixel        Line         Pixel"
570    FOR I=1 TO N
580    PRINT USING 590;Counter(I),Ynew(I),Xnew(I),Yold(I),Xold(I)
```

```
590    IMAGE DDD, 6X,DDDDDDD,4X,DDDDDDD, 6X,DDDDDDD,6X,DDDDDDD
600    NEXT I
610    LINPUT "Are values correct -Y or N ?",Ans$
620    IF Ans$[1,1]="Y" THEN GOTO Cont
630    INPUT "Do you wish to delete  values YES or NO ?",Aq$
640    IF Aq$[1,1]<>"Y" THEN GOTO 840
650    INPUT "How many controls to delete ?",Number
660    DIM Check(50)
670    REDIM Check(Number)
680    PRINT "Enter control numbers in any order"
690    MAT INPUT Check
700    MAT SORT Check(*) DES
710    FOR Z=1 TO Number
720    N=N-1
730    MAT SEARCH Counter(*),LOC(Check(Z));Istart
740    FOR I=Istart TO N
750    Xold(I)=Xold(I+1)
760    Yold(I)=Yold(I+1)
770    Xnew(I)=Xnew(I+1)
780    Ynew(I)=Ynew(I+1)
790    Counter(I)=Counter(I+1)
800    NEXT I
810    NEXT Z
820    REDIM Xold(N),Xnew(N),Yold(N),Ynew(N)
830    GOTO 530
840    INPUT "Enter control number for incorrect values",K
850    PRINT LIN(20),SPA(5),"Ynew,Xnew,Yold,Xold=";Ynew(K),Xnew(K),Yold(K),Xold(K)
860    INPUT "Enter correct values for all 4 parameters",Ynew(K),Xnew(K),Yold(K),Xold(K)
870    GOTO 530
880 Cont: LINPUT "Do you wish to list control points on printer.",List$
890    IF List$[1,1]<>"Y" THEN GOTO 980
900    PRINTER IS 0
910    PRINT "Control no        NEW                      OLD"
920    PRINT "              Line        Pixel          Line        Pixel"
930    FOR I=1 TO N
940    PRINT USING 590;Counter(I),Ynew(I),Xnew(I),Yold(I),Xold(I)
950    IMAGE DDD,7X,DDDDD,2X,DDDDD, 9X,DDDDD,2X,DDDDD
960    NEXT I
970    PRINT LIN(5)
980    CALL Bilinear(Xnew(*),Ynew(*),Xold(*),R(*),N)
990    CALL Bilinear(Xnew(*),Ynew(*),Yold(*),S(*),N)
1000          ! Where: Xold=R(1)*Xnew+R(2)*Ynew+R(3)
1010          !        Yold=S(1)*Xnew+S(2)*Ynew+S(3)
1020          ! Thus to transform a night image the new DN values are computed:
1030          ! DNnew(Pixel,Line)=DNold(P,L)
1040          ! where P=R(1)*Pixel+R(2)*Line+R(3)
1050          !   and L=S(1)*Pixel+S(2)*Line+S(3)
1060   PRINTER IS 0
1070   Del12=R(1)*S(2)-S(1)*R(2)
1080   Del13=R(3)*S(1)-S(3)*R(1)
1090   Del23=R(2)*S(3)-R(3)*S(2)
1100   Px1(1)=S(2)-R(2)
1110   Px1(2)=S(2)*Pmax-R(2)
1120   Px1(3)=S(2)*Pmax-R(2)*Lmax
1130   Px1(4)=S(2)-R(2)*Lmax
1140   Lx1(1)=R(1)-S(1)
1150   Lx1(2)=R(1)-S(1)*Pmax
1160   Lx1(3)=R(1)*Lmax-S(1)*Pmax
1170   Lx1(4)=R(1)*Lmax-S(1)
1180   MAT Lx1=Lx1/(Del13)
```

```
1190  MAT Lxl=Lxl/(Del12)
1200  MAT Pxl=Pxl+(Del23)
1210  MAT Pxl=Pxl/(Del12)
1220  MAT SEARCH Pxl(*),MAX;Pxmax
1230  MAT SEARCH Pxl(*),MIN;Pxmin
1240  MAT SEARCH Lxl(*),MAX;Lxmax
1250  MAT SEARCH Lxl(*),MIN;Lxmin
1260  Dpix=Pxmax-Pxmin+1
1270  Dlin=Lxmax-Lxmin+1
1280  Alpha=R(1)*(Pxmin-1)+R(2)*(Lxmin-1)+R(3)
1290  Beta=S(1)*(Pxmin-1)+S(2)*(Lxmin-1)+S(3)
1300  C2=Alpha*S(2)-Beta*R(2)
1310  C3=Alpha*S(1)-Beta*R(1)
1320  Pix_old_mean=SUM(Xold)/N
1330  Pix_new_mean=SUM(Xnew)/N
1340  Lin_new_mean=SUM(Ynew)/N
1350  Lin_old_mean=SUM(Yold)/N
1360  Del=Del12
1370  Pix_off=S(2)/Del*Pix_old_mean-R(2)/Del*Lin_old_mean-C2/Del-Pix_new_mean
1380  Lin_off=-(S(1)/Del)*Pix_old_mean+R(1)/Del*Lin_old_mean+C3/Del-Lin_new_mean
1390  Cos_theta=(R(1)+S(2))/2
1400  Sin_theta=(S(1)-R(2))/2
1410  DEG
1420  Theta=ATN(Sin_theta/Cos_theta)
1430  Mag_x=SQR(R(1)^2+S(1)^2)
1440  Mag_y=SQR(R(2)^2+S(2)^2)
1450  PRINT "SOLUTION FOR:"
1460  PRINT Name$
1470  PRINT
1480  PRINT "Original image is ";Pmax;" pixels by ";Lmax;" lines."
1490  PRINT
1500  PRINT
1510  STANDARD
1520  PRINT "R=";R(1);R(2);Alpha
1530  PRINT
1540  PRINT "S=";S(1);S(2);Beta
1550  PRINT
1560  PRINT "BK moc:R(3)= ";R(3);" S(3)= ";S(3)
1570  PRINT
1580  PRINT "where:  DNnew(Pixel,Line)=DNold(P,L)"
1590  PRINT
1600  PRINT "        P=R(1)*Pixel+R(2)*Line+R(3)"
1610  PRINT "        L=S(1)*Pixel+S(2)*Line+S(3)"
1620  PRINT
1630  PRINT " New image size: ";Dpix;" pixels by ";Dlin;" lines."
1640  PRINT
1650  PRINT " Mean rotation angle :";Theta
1660  PRINT " Magnification :-X ";Mag_x;" -Y ";Mag_y
1670  PRINT
1680  PRINT " Offset:     Pixels ";Pix_off
1690  PRINT "             Lines  ";Lin_off
1700  PRINTER IS Printer
1710 Plotting: CALL Plot("Initial controls:",Xold(*),Yold(*),Xnew(*),Ynew(*),N,Name$,Counter(*)
1720  Residual=0
1730  PRINTER IS 0
1740  Max_residual=0
1750  PRINT
1760  PRINT " Control no.            Yt                  Xt                        Residual"
1770  Del=Del12
1780  C2= Del23
```

```
1790  C3=Del13
1800  FOR I=1 TO N
1810  Xt(I)=(Xold(I)*S(2)-Yold(I)*R(2)-C2)/Del
1820  Yt(I)=-(Xold(I)*S(1)-Yold(I)*R(1)-C3)/Del
1830  Max_red=(Xt(I)-Xnew(I))^2+(Yt(I)-Ynew(I))^2
1840  PRINT Counter(I),Xt(I),Yt(I),SQR(Max_red)
1850  Residual=Max_red+Residual
1860  Max_residual=MAX(Max_red,Max_residual)
1870  IF Max_residual=Max_red THEN Imax_res=Counter(I)
1880  NEXT I
1890  Max_res=SQR(Max_residual)
1900  Residual=SQR(Residual/(N-1))
1910  FIXED 2
1920  PRINTER IS 0
1930  PRINT
1940  PRINT
1950  FIXED 2
1960  PRINT " Mean residual vector length =";Residual;" pixels"
1970  PRINT " Max residual vector length =";Max_res;" pixels";" at point ";Imax_res
1980  PRINT
1990  CALL Plot("Transformed controls:",Xt(*),Yt(*),Xnew(*),Ynew(*),N,Name$,Counter(*))
2000  GOTO Enter       !
2010  END
2020  SUB Bilinear(X(*),Y(*),Z(*),M(*),N)
2030          ! Z=M(1)*X+M(2)*Y+M(3)     LEAST SQUARES ESTIMATE FOR M
2040  OPTION BASE 1
2050  DIM S(100,3),Transpose(3,100),Inverse(100,100),Dum(100,100),Z1(100,1),M1(3,1)
2060  REDIM S(N,3),Transpose(3,N),Inverse(N,N),Dum(N,N),Z1(N,1)
2070  FOR I=1 TO N
2080  S(I,1)=X(I)
2090  S(I,2)=Y(I)
2100  S(I,3)=1
2110  Z1(I,1)=Z(I)
2120  NEXT I
2130  MAT Transpose=TRN(S)
2140  MAT Dum=Transpose*S
2150  MAT Inverse=INV(Dum)
2160  MAT Dum=Inverse*Transpose
2170  MAT M1=Dum*Z1
2180  FOR J=1 TO 3
2190  M(J)=M1(J,1)
2200  NEXT J
2210  SUBEND
2220  SUB Plot(Plot_title$,Xnew(*),Ynew(*),Xold(*),Yold(*),N,Name$,Counter(*))
2230  OPTION BASE 1
2240  INTEGER I
2250  STANDARD
2260  PLOTTER IS 13,"GRAPHICS"
2270  GRAPHICS
2280  LOCATE 5,150,5,95
2290  MOVE 10,97
2300  LABEL Plot_title$&"  "&Name$
2310  MAT SEARCH Xnew,MAX;Xmax
2320  MAT SEARCH Xold,MAX;Xmax1
2330  Xmax=MAX(Xmax,Xmax1)
2340  MAT SEARCH Yold,MAX;Ymax1
2350  MAT SEARCH Ynew,MAX;Ymax
2360  Ymax=MAX(Ymax,Ymax1)
2370  MAT SEARCH Ynew,MIN;Ymin
2380  MAT SEARCH Yold,MIN;Ymin1
```

```
2390  Ymin=MIN(Ymin,Ymin1)
2400  MAT SEARCH Xold,MIN;Xmin1
2410  MAT SEARCH Xnew,MIN;Xmin
2420  Xmin=MIN(Xmin,Xmin1)
2430  SHOW Xmin-25,Xmax+25,Ymax+25,Ymin-25
2440  LINE TYPE 1
2450  FRAME
2460  LORG 2
2470  CSIZE 2.5
2480  FOR I=1 TO N
2490  MOVE Xold(I),Yold(I)
2500  DRAW Xnew(I),Ynew(I)
2510  Xx=Xnew(I)-Xold(I)
2520  Yy=Ynew(I)-Yold(I)
2530  IF Yy=0 THEN GOTO 2550
2540  LDIR Xx,Yy
2550  MOVE Xnew(I),Ynew(I)
2560  IF Xx>=0 THEN LABEL ">"&VAL$(Counter(I))
2570  IF Xx>=0 THEN GOTO 2620
2580  LORG 8
2590  LDIR -Xx,-Yy
2600  LABEL VAL$(Counter(I))&"<"
2610  LORG 2
2620  NEXT I
2630  SETGU
2640  LDIR 0
2650  CSIZE 3.3
2660  MOVE 69,3
2670  LORG 5
2680  LABEL "CONT to continue;DUMP GRAPHICS for hard copy"
2690  PAUSE
2700  EXIT GRAPHICS
2710  SUBEND
2720  END
```

```
10     !  RAPFIT  To perform the regional atmospheric fitting.
20     !  Program language is extended Basic.
30     !  Program written by K.Watson
40     !              Pmapping algorithm development.
50     !  ENTER: SITE LATITUDE AND SOLAR DECLINATION.
60     !  PROGRAM COMPUTES Tday AND Tnite FOR THE HCMM TIMES ,
70     !  VARYING THE Tsky AND Sky_factor.
80     !  INPUT OBSERVATIONAL DATA:
90     !  Tdayo,Tniteo;Albeoo
100    !  COMPUTE THE Standard Deviation for temp data - Shade print output.
110   Picons=SQR(PI*3600*24)
120   OPTION BASE 1
130   DIM Flux1(24),Temp(24),Phi(24),Flux(24),String$(10)[80]
140   DIM P1(24,24),P5(24,24),Cosz(24),Dev(20,20)
150   INTEGER I,K,L,Delik
160   DEG
170   ! RECALL THE Phi's.
180   ASSIGN #1 TO "Phi_m"
190   READ #1;M
200   IF M=24 THEN GOTO 230
210   PRINT "ERROR : ;";M;" P   VALUES - SHOULD BE 24"
220   STOP
230   READ #1;Phi(*)
240   ASSIGN #1 TO "Phi_m"
250   INPUT "Enter the site latitude(Degrees) ",Latitude
260   INPUT "Enter the solar declination(Degrees) ",Solar_dec
270   OUTPUT 9;"R"
280   ENTER 9;T$
290   W=PI/12
300   W1=PI/(12*3600)
310   So=1360
320   Sigma=5.67E-8
330   !           FIXED PARAMETERS.
340   Emissivity=1
350   Slope=0
360   Azimuth=0
370   Flux_diffuse=0
380   INPUT "Enter the mean day Temp (DEG K) from scene data",Tdayo
390   INPUT "Enter the mean nite Temp (DEG K) from scene data",Tniteo
400   C1=COS(Latitude)*COS(Solar_dec)
410   S1=SIN(Latitude)*SIN(Solar_dec)
420   Cosz(1)=C1+S1
430   FOR K=2 TO 24
440   Cosz(K)=C1*COS((K-1)*15)+S1
450   IF Cosz(K)<0 THEN Cosz(K)=0
460   NEXT K
470   Cz1=SIN(Slope)*SIN(Azimuth)*COS(Solar_dec)
480   Cz2=COS(Latitude)*COS(Slope)-SIN(Slope)*COS(Azimuth)*SIN(Latitude)
490   Cz2=Cz2*COS(Solar_dec)
500   Cz3=SIN(Latitude)*COS(Slope)+COS(Latitude)*COS(Azimuth)*SIN(Slope)
510   Cz3=Cz3*SIN(Solar_dec)
520   INPUT "Enter mean A[illegible]",Albedo
530   Inertia=1500
540   Deviation2=10000
550   Cons2=Inertia/Picons
560   !           LOOP PARAMETERS.          FIRST LOOP
570   PRINTER IS 0
580   PRINT " Tsky","Sky_factor","   Deviation"
590 Return:  PRINTER IS 16
```

```
600    INPUT "Tsky_max",Tsky_max
610    INPUT "Tsky_min",Tsky_min
620    INPUT "Dtsky",Dtsky
630    INPUT "Sky_factor_max",Sky_factor_max
640    INPUT "Sky_factor_min",Sky_factor_min
650    INPUT "Dsky_factor",Dsky_factor
660    Dev_min=1E9
670 Ken: FOR Tsky=Tsky_min TO Tsky_max STEP Dtsky
680    PRINT "Tsky=";Tsky
690    Flux_sky=Sigma*Tsky^4
700    FOR Sky_factor=Sky_factor_min TO Sky_factor_max STEP Dsky_factor
710    OUTPUT 9;"R"
720    ENTER 9;Month,Day,Hour,Minute,Second
730    PRINT TAB(20);"Sky_factor=";Sky_factor,Hour;":";Minute
740    Flux_direct=So*(1-Sky_factor)
750    FOR I=1 TO 24
760    X=(I-1)*15
770     Cosz1=Cosz(I)
780    IF Cosz1<0 THEN Cosz1=0
790    Flux1(I)=(1-Albedo)*(Flux_diffuse+Cosz1*Flux_direct)+Emissivity*Flux_sky
800    NEXT I
810    Sum=0
820    FOR I=1 TO 24
830    Sum=Flux1(I)+Sum
840    NEXT I
850    Sum=Sum/M
860    Vo=(Sum/(Emissivity*Sigma))^.25
870    Alpha=3*Emissivity*Sigma*Vo^3
880    Cons=Cons2/Alpha
890    Cons1=Alpha*4/3
900    FOR I=1 TO 24
910    Flux(I)=Flux1(I)+Alpha*Vo
920    NEXT I
930    FOR I=1 TO 24
940    FOR K=1 TO 24
950    L=I-K+1
960    IF L<1 THEN L=L+24
970    Delik=0
980    IF I=K THEN Delik=1
990    P5(I,K)=Cons2*Phi(L)+Cons1*Delik
1000   NEXT K
1010   NEXT I
1020   MAT P1=INV(P5)
1030   !  FORM Temp
1040   MAT Temp=P1*Flux
1050   ! REMEMBER Temp(K) is at time K-1 hours.(measured from noon)
1060   Tday=(Temp(2)+Temp(3))*.5
1070   Tnite=(Temp(14)+Temp(15))*.5
1080   I1=(Tsky-Tsky_min)/Dtsky+1
1090   J1=(Sky_factor-Sky_factor_min)/Dsky_factor+1
1100   Dev(I1,J1)=SQR((Tday-Tdayo)^2+(Tnite-Tniteo)^2)
1110   Dev_min=MIN(Dev_min,Dev(I1,J1))
1120   IF Dev(I1,J1)=Dev_min THEN Tsky_opt=Tsky
1130   IF Dev(I1,J1)=Dev_min THEN Sky_factor_opt=Sky_factor
1140   PRINTER IS 0
1150   PRINT Tsky,Sky_factor,Dev(I1,J1);I1;J1
1160   PRINTER IS 16
1170   NEXT Sky_factor
1180   NEXT Tsky
1190   BEEP
```

```
1200  PRINT "Optimum fit: Tsky =";Tsky_opt,"Sky_factor =";Sky_factor_opt
1210  GOTO Return
1220  INPUT "Enter THE I(Tsky) AND J(Sky_factor) VALUES",I,J
1230  Tskyo=210+(Io-1)*10
1240  Sky_factoro=(Jo-1)*.05
1250  !          LOOP PARAMETERS.          SECOND LOOP
1260  FOR Tsky=Tskyo-2 TO Tskyo+2 STEP 1
1270  PRINT "Tsky=";Tsky
1280  Flux_sky=Sigma*Tsky^4
1290  FOR Sky_factor=Sky_factoro-.02 TO Sky_factor+.02 STEP .01
1300  OUTPUT 9;"R"
1310  ENTER 9;Month,Day,Hour,Minute,Second
1320  PRINT TAB(20);"Sky_factor=";Sky_factor,Hour;":";Minute
1330  Flux_direct=So*.6*(1-Sky_factor)
1340  FOR I=1 TO 24
1350  X=(I-1)*15
1360   Cosz1=Cosz(I)
1370  IF Cosz1<0 THEN Cosz1=0
1380  Flux1(I)=(1-Albedo)*(Flux_diffuse+Cosz1*Flux_direct)+Emissivity*Flux_sky
1390  NEXT I
1400  Sum=0
1410  FOR I=1 TO 24
1420  Sum=Flux1(I)+Sum
1430  NEXT I
1440  Sum=Sum/M
1450  Vo=(Sum/(Emissivity*Sigma))^.25
1460  Alpha=3*Emissivity*Sigma*Vo^3
1470  Cons=Cons2/Alpha
1480  Cons1=Alpha*4/3
1490  FOR I=1 TO 24
1500  Flux(I)=Flux1(I)+Alpha*Vo
1510  NEXT I
1520  FOR I=1 TO 24
1530  FOR K=1 TO 24
1540  L=I-K+1
1550  IF L<1 THEN L=L+24
1560  Delik=0
1570  IF I=K THEN Delik=1
1580  P5(I,K)=Cons2*Phi(L)+Cons1*Delik
1590  NEXT K
1600  NEXT I
1610  MAT P1=INV(P5)
1620  !  FORM Temp
1630  MAT Temp=P1*Flux
1640  ! REMEMBER Temp(K) is at time K-1 hours.(measured from noon)
1650  Tday=(Temp(2)+Temp(3))*.5
1660  Tnite=(Temp(14)+Temp(15))*.5
1670  I1=(Tsky-250)/5+1
1680  J1=Sky_factor/.05+1
1690  Dev(I1,J1)=SQR((Tday-Tdayo)^2+(Tnite-Tniteo)^2)
1700  PRINT Tsky,Sky_factor,Dev(I1,J1)
1710  NEXT Sky_factor
1720  NEXT Tsky
1730  Min_dev=1E15
1740  FOR I=1 TO 5
1750  FOR J=1 TO 6
1760  Min_dev=MIN(Min_dev,Dev(I,J))
1770  IF Dev(I,J)=Min_dev THEN Io=I
1780  NEXT J
```

```
1790  NEXT I
1800  Tsky=Tskyo+(Io-3)*1
1810  Sky_factor=Sky_factoro+(Jo-3)*.01
1820  STOP
1830  END
```

```
      PROGRAM GEOMX4
C..... ***************************************************************
C.....
C..... REMOTE SENSING ARRAY PROCESSING PROCEDURES
C..... U. S. GEOLOGICAL SURVEY, DENVER, COLORADO
C..... BRANCH OF PETROPHYSICS AND REMOTE SENSING
C..... DON L. SAWATZKY
C.....
C..... ***************************************************************
C
C     GEOMX4 GENERATES A RECTIFIED IMAGE FILE FROM A DISTORTED IMAGE
C FILE AND FROM COEFFICIENTS FOR RECTIFICATION, R AND S, DETERMINED FOR AN
C AFFINE TRANSFORMATION OF THE DISTORTED FILE.
C INPUT FILE STRUCTURE CONSISTS OF A HEADER RECORD CONTAINING TWO
C INTEGERS FOR LINE LENGTH, LENREC, IN PIXELS AND NUMBER OF LINES,
C NORECS.  NORECS NUMBER OF DATA RECORDS FOLLOW, EACH RECORD CONTAINING LENREC
C BYTES OF 8-BIT DATA.  OUTPUT FILE HEADER RECORD CONTAINS TWO INTEGERS OF LINE
C LENGTH, NPXOUT, AND NUMBER OF RECORDS, LMAX.  INPUT PARAMETERS, IPIXIN AND NPI
C XIN, ALLOW TAKING A SUBSET OF THE INPUT FILE.  OUTPUT PARAMETERS LMAX, MNPIX
C , AND MXPIX ARE SELECTED ON THE LINE LENGTH OF THE INPUT FILE AND DEGREE
C OF ROTATION REQUIRED FOR RECTIFICATION.  SECTIONS OF THE OUTPUT FILE OF LENGTH
C LMAX AND CONTAINING PIXELS MNPIX TO MXPIX ARE GENERATED BY ONE OR MORE ITER
C ATIONS OF THIS PROGRAM.  SECTIONS ARE CONCATENATED IN SUBSEQUENT PROCESSING.
C SECTIONING THE OUTPUT FILE IS DONE IN RESPONSE TO THE MESSAGE: "INBUF ARRAY
C TOO SMALL."
C
C.....DECLARATIONS
      REAL R(3),S(3)
      LOGICAL*1 INBUF(200000),OUTBUF(3000)
      INTEGER FCBIN(35),FCBOUT(35)
C.....
C.....SET PARAMETERS
      WRITE(6,99)
99    FORMAT(1X,'ENTER PIXEL/LINE COEFFICIENTS ':)
      READ(5,96) R,S
      WRITE(6,98)
98    FORMAT(1X,'ENTER INPUT FIRST PIXEL, NO. PIXELS')
      READ(5,96) IPIXIN,NPIXIN
      WRITE(6,97)
97    FORMAT(1X,'ENTER MAX. OUTPUT LINES,MIN/MAX PIXEL ':)
      READ(5,96) LMAX,MNPIX,MXPIX
96    FORMAT(G16.0)
C.....
C.....OPEN DATA FILE TO TRANSFORM
      READ(8) LENREC,NORECS
C.....SETUP WORK ARRAY
      NRECS=MIN(200000/LENREC,NORECS)
      MXLINE=NRECS
      MNLINE=1
      J1=LENREC*MOD(I,NRECS)+1
      J2=J1+LENREC-1
      DO 90 I=1,NRECS
90    READ(8) (INBUF(J),J=J1,J2)
C.....
C.....OPEN OUTPUT DATA FILE
      NPXOUT=MXPIX-MNPIX+1
      IF(NPXOUT.LE.3000.AND.NPIXIN.LE.3000)GO TO 110
100   STOP ' ?DATA FILES EXCEED BUFFER WIDTH.'
110   WRITE(9) NPXOUT,LMAX
C.....READ/WRITE LOOP
      DO 210 LINE=1,LMAX
      DO 200 IPX=MNPIX,MXPIX
```

```
      INPX=R(1)*(IPX) + R(2)*(LINE) + R(3)
      IF(INPX.LT.1.OR.INPX.GT.NPIXIN) THEN
      OUTBUF(IPX-MNPIX+1)=.FALSE.
      ELSE
      INLINE=S(1)*(IPX) + S(2)*(LINE) + S(3)
      IF(INLINE.LT.1.OR.INLINE.GT.NORECS) THEN
      OUTBUF(IPX-MNPIX+1)=.FALSE.
      ELSE
C.....CHECK LIST FOR SCANLINE IN WORK ARRAY
      IF(INLINE.GE.MNLINE.AND.INLINE.LE.MXLINE) GOTO120
C.....ELSE READ SCANLINE INTO LIST AND WORK ARRAY
      IF(INLINE.LT.MNLINE) STOP'INBUF ARRAY TOO SMALL!!'
      DO 115 I=MXLINE+1,INLINE
      IREC=MOD(I,NRECS)*LENREC
115   READ(8,REC=INLINE) (INBUF(J),J=IREC+1,IREC+NPXIN)
      MXLINE=INLINE
      MNLINE=MXLINE-NRECS+1
120   OUTBUF(IPX-MNPIX+1)=INBUF(LENREC*MOD(INLINE,NRECS)+INPX)
      ENDIF
      ENDIF
200   CONTINUE
210   WRITE(9) (OUTBUF(J),J=1,NPXOUT)
C.....
C.....FINIS
300   STOP
      END
```

```
      PROGRAM HCMTID
C   THIS PROGRAM COMPUTES A RELATIVE THERMAL INERTIA AND TEMP DIFF
C    IMAGE FILES FROM HCMM DATA.
C
      DIMENSIONI1(35),I2(35),I3(35),I4(35),IB1(2000),IB2(2000),
     & IB3(2000)
      DIMENSION TEMP(256),ALB(256),I5(35)
      DIMENSION I6(35),IDUM(2000),IDT(2000)
      DATA I1/3*0,1,1,30*0/,I2/3*0,1,1,30*0/,I3/3*0,1,1,30*0/
      DATA I4/16,0,0,1,1,30*0/,I5/8,0,0,1,1,30*0/,I6/8,0,0,1,1,30*0/
      INTEGER*2 IT(2000)
C
C   OPEN NOON THERMAL FILE
C
      WRITE(6,FMT='('' OPEN DAY THERMAL FILE'')')
      CALL DISKIO (0,12,IB1,I1)
C
C   OPEN NIGHT THERMAL FILE
C
      WRITE(6,FMT='('' OPEN NIGHT THERMAL FILE'')')
      CALL DISKIO (0,13,IB2,I2)
C
C   OPEN NOON ALBEDO FILE"
C
      WRITE(6,FMT='('' OPEN NOON ALBEDO FILE'')')
      CALL DISKIO (0,14,IB3,I3)
C
C   OPEN THERMAL INERTIA OUTPUT FILE
C
      WRITE(6,FMT='('' OPEN THERMAL INERTIA OUTPUT FILE'')')
      W=I1(2)
      X=I2(2)
      Y=I3(2)
      W1=I1(3)
      X1=I2(3)
      Y1=I3(3)
      MAXP=AMIN1(W,X,Y)
      MAXL=AMIN1(W1,X1,Y1)
      I4(2)=MAXP
      I4(3)=MAXL
      CALL DISKIO (0,15,0,I4)
C
C   OPEN TEMP DIFF OUTPUT FILE
C
      WRITE(6,FMT='('' OPEN TEMP DIFF OUTPUT FILE'')')
      I5(2)=MAXP
      I5(3)=MAXL
      CALL DISKIO (0,16,0,I5)
C
C   OPEN DUMMY FILE
C
      WRITE(6,FMT='('' OPEN DUMMY FILE'')')
      I6(2)=MAXP
      I6(3)=MAXL
      CALL DISKIO (0,17,0,I6)
C
C   INPUT AVERAGE PARMS
C
      WRITE (6,FMT='('' ENTER AVERAGE VALUES A,TD,TN'')')
      ACCEPT * ,AAVE,ATD,ATN
      TYPE * ,AAVE,ATD,ATN
      WRITE (6,FMT='('' ENTER LATITUDE AND SOLAR DEC IN DEG'')')
```

```
      ACCEPT * ,XLAM,DELTA
      TYPE * ,XLAM,DELTA
      XLAM=XLAM*0.017453
      DELTA=DELTA*0.017453
      DEG=1./(COS(XLAM-DELTA))
      QO=1353*(1.-.2*SQRT(DEG))
      C=-QO*82.5186*(COS(XLAM)+0.46*DELTA*SIN(XLAM))
      B=(ATD-ATN)*1500-C*AAVE
      TYPE * ,QO
      TYPE * ,C
      TYPE * ,B
      WRITE (6,FMT='('' P REL = (B+C*ALB)/DT'')')
C
C  COMPUTE TEMP AND ALB CALIBRATION FILES
C
      DO 2 K=1,256
  2     ALB(K)=(K-1)*0.00392157
      C1=14421.587
      C2=1251.1591
      C3=-118.21376
      DO 11 LK=1,256
 11     TEMP(LK)=C2/(ALOG(C1/(LK-1-C3)+1))
C
C  MAIN READ/WRITE LOOP
C
      DO 3 I=1,MAXL
      CALL DISKIO (9,12,IB1,I1)
     CALL UNPACK(IB1,I1(2))
      CALL DISKIO (9,13,IB2,I2)
     CALL UNPACK(IB2,I2(2))
      CALL DISKIO (9,14,IB3,I3)
     CALL UNPACK(IB3,I3(2))
C
        DO 4 K=1,MAXP
          NUM1=IB1(K)+1
          NUM2=IB2(K)+1
          NUM3=IB3(K)+1
          TD=TEMP(NUM1)
          TN=TEMP(NUM2)
          AA=ALB(NUM3)
          IDUM(K)=255
          S=TD-TN
          X=(AA-AAVE)*100
          Y=ATD-TD
          IF (X.GE.2.AND.Y.GE.15) GO TO 21
          IF (TN.LE.265) GO TO 21
          Z=-S
          IF (S.LE.0.AND.Z.LE.10) GO TO 22
          IF (S.LE.0) GO TO 21
          IT(K)=(B+C*AA)/S
          IDT(K)=S
          IF (IT(K).EQ.3550) IT(K)=3560
          IF (IT(K).EQ.1000) IT(K)=990
          GO TO 4
 21       IT(K)=1000
          IDT(K)=255
          IDUM(K)=0
        GO TO 4
 22     IT(K)=3550
        IDT(K)=0
        IDUM(K)=255
  4     CONTINUE
        CALL DISKIO (10,15,IT,I4)
```

```
      CALL PACK(IDT,I5(2))
         CALL DISKIO (10,16,IDT,I5)
      CALL PACK(IDUM,I6(2))
         CALL DISKIO (10,17,IDUM,I6)
 3       CONTINUE
C
C  CLOSE FILES
C
      CALL DISKIO (6,12,0,I1)
      CALL DISKIO (6,13,0,I2)
      CALL DISKIO (6,14,0,I3)
      CALL DISKIO (6,15,0,I4)
      CALL DISKIO (6,16,0,I5)
      CALL DISKIO (6,17,0,I6)
      STOP
      END
```

```
10      ! PROFLE     Profiling routines. 3/2/81
20      ! Program language is extended Basic.
30      ! Program written by K.Watson
40     OPTION BASE 1
50     DIM Tday(1500),Tnite(1500),Elev(1500),X(1500),Y(1500),Dum(1500),Derv(1500),Inert(150
- 00),Dt(1500),Topo(1500),Mean(1500)
60     DIM R(2000),Z(2000),X2(2000),Topx(2000),S$[80],A$(5)[41]
70     INTEGER Dn(4000)
80     PRINTER IS 16
90     Elev_corr=0        ! Initialize elevation correction indicator
100    Enable=0           ! Initialize for profile plotting
110    INPUT "Enter profile ie. A,B",Profile$[1,1]
120    Profile$=Profile$&Profile$&" "
130    INPUT "Enter area name ie.PRB",Area$
140    File_sp$=Area$&Profile$[1,1]
150 Function_keys: !
160         ON KEY #0 GOTO Topo_gen
170         ON KEY #1 GOTO Image_gen
180         ON KEY #2 GOTO Prof_plot
190         ON KEY #3 GOTO Feature
200         ON KEY #4 GOTO File_edit
210         ON KEY #5 GOTO Cross_cor
220         ON KEY #6 GOTO Cross_plot_sngl
230         ON KEY #7 GOTO Cross_plot_mult
240         ON KEY #8 GOTO Topo_resample
250         ON KEY #9 GOTO Elev_correct
260         ON KEY #10 GOTO Report_plot
270         IF Elev_corr=1 THEN Profile$=Profile$&" elev corr"
280     MASS STORAGE IS ":C"
290     EXIT GRAPHICS
300     PRINT PAGE
310     PRINT " KEY #0 Generate topo binary file from PERKIN output"
320     PRINT " KEY #1 Generate image binary file"
330    .PRINT " KEY #2 Plot a profile"
340     PRINT " KEY #3 Select a feature for matching profiles"
350     PRINT " KEY #4 File edit"
360     PRINT " KEY #5 Cross correlate two images"
370     PRINT " KEY #6 Cross plot two data files(report)"
380     PRINT " KEY #7 Cross plot multiple data files"
390     PRINT " KEY #8 Resample the topo data to match images"
400     PRINT " KEY #9 Determine elevation correction to temp data"
410     PRINT " KEY #10 Profile plotting(report)"
420     PRINT " MASS STORAGE SET TO :C"
430     DISP "Select option"
440        GOTO 430
450        !
460        !               **********************
470        !
480 Topo_gen: ! To generate topo binary file from digitized records.
490     OVERLAP
500     BUFFER #1
510     PRINT PAGE
520     INPUT "Enter number of input files from DIGIND",M
530     File$="ToppBB"    ! ****************************************
540     DISP "Generating topo file."
550     I=0
560     FOR N=1 TO M
570     ON END #1 GOTO 640
580     ASSIGN #1 TO File$
```

```
590    READ #1;K
600    REDIM R(K)
610    READ #1;Curve$
620    READ #1;Xlower,Xupper
630    READ #1;R(*)
640    ASSIGN #1 TO *
650    FOR L=1 TO K
660    Z(L+I+2)=R(L)*12*.0254 ! Convert from ft to m.
670    NEXT L
680    I=I+K
690    NEXT N
700    REWIND ":T15"
710    REDIM Z(I+2)
720    Z(1)=I
730    Z(2)=.15875        ! km   . Assumes 1/40 " spacing on 1:250,000 map
740    Fileout$="Topo"&Profile$[1,2]
750    FCREATE Fileout$,52
760    FPRINT Fileout$,Z(*)
770    DISP "Finished"
780    WAIT 500
790    SERIAL
800    GOTO Function_keys
810    !
820      !            **********************
830      !
840 Image_gen:  !  To generate image binary files.
850    OVERLAP
860    BUFFER #1
870    PRINT PAGE
880    !     Regular Perkin image files
890    !
900    LINPUT "Enter file type ie Tday,Tnite,Refl",Filex$
910    DISP "Generating image file."
920    X$=Profile$[1,1]&":T15"
930    IF Filex$="Tday" THEN F$="TD"&X$
940    IF Filex$="Tnite" THEN F$="TN"&X$
950    IF Filex$="Refl" THEN F$="RD"&X$
960    INPUT "Enter starting pixel and line",Ps,Ls
970    INPUT "Enter ending pixel and line",Pn,Ln
980    INPUT "Enter number of data blocks ",No_blocks
990    C1=(Ls-Ln)/(Ps-Pn)
1000   J=1      ! Profile element counter
1010   I=1     ! Block no
1020   FOR I=1 TO No_blocks      !  INSERT FAST ALGORITHM HERE.
1030   CAT TO A$(*);F$&VAL$(I)
1040   IF LEN(A$(1))<>0 THEN GOTO 1090
1050   REWIND ":T15"
1060   PRINT "F$&VAL$(I) not on tape.Insert correct tape and CONT"
1070   PAUSE
1080   GOTO 1030
1090                ASSIGN #1 TO F$&VAL$(I)     !
1100   READ #1;S$
1110   N=POS(S$,"Lines")
1120   Lines=VAL(S$[N+5,N+7])
1130   M=POS(S$,"Pixels")
1140   Pixels=VAL(S$[M+6,M+8])
1150   PRINT "Lines,Pixels=";Lines,Pixels
1160   REDIM Dn(Pixels*Lines)
1170   READ #1;Dn(*)
1180   FOR K=1 TO Pixels
```

```
1190  Yy=C1*(K-1)+1
1200  L1=INT(Yy)
1210  IF Yy-L1>.5 THEN L1=L1+1
1220  Z(J)=Dn((L1-1)*Pixels+K)
1230 ! PRINT J,Z(J)        ! Use for editing.
1240  J=J+1   ! Increment profile counter
1250  NEXT K
1260  ASSIGN #1 TO *
1270  NEXT I
1280  REWIND ":T15"
1290  J=J-1   ! Reset pixel counter
1300   REDIM Z(J)
1310  K1=14421.587    ! Temp calib Dn to Temp
1320  K2=1251.1591
1330  K3=-118.21376
1340  Dist=SQR((Pn-Ps)^2+(Ln-Ls)^2)*.47717/J          !   km approx  units
1350  REDIM Z(J),X(J)
1360  IF (Filex$="Tday") OR (Filex$="Tnite") THEN GOTO Temp_cal
1370  IF Filex$="Refl" THEN GOTO Refl_cal
1380 Temp_cal: FOR I=1 TO J
1390  Z(I)=K2/LOG(K1/(Z(I)-K3)+1)
1400  IF Z(I)<260 THEN Z(I)=260
1410  NEXT I
1420  GOTO Bin_store
1430 Refl_cal: FOR I=1 TO J
1440  Z(I)=Z(I)/255*100              ! % refl
1450  NEXT I
1460  GOSUB Bin_store
1470  GOTO Function_keys
1480 Bin_store: !
1490  DISP "Binary store"
1500  Dum(1)=J      ! No_values
1510  Dum(2)=Dist   ! Dx increment in km.
1520  FOR I=3 TO J+2
1530   Dum(I)=Z(I-2)     ! Normal statement
1540  NEXT I
1550  REDIM Dum(J+2)
1560  Filename$=Filex$[1,4]&Profile$[1,2]
1570  FCREATE Filename$,52
1580  FPRINT Filename$,Dum(*)
1590  PRINT PAGE
1600  DISP "Finished"
1610  SERIAL
1620  RETURN
1630  !
1640  !           ***************************
1650  !
1660 Prof_plot: ! On CRT or at 1:1,000,000 on 9872S.
1670  INPUT "Select plotter option: 0 CRT , 1 9872S",Plotter
1680  PRINT PAGE
1690  GOSUB File_read
1700  GOSUB File_plot
1710  IF Plotter=0 THEN EXIT GRAPHICS
1720  IF V=1 THEN GOTO 1690
1730  GOTO Function_keys
1740 File_read: INPUT "Enter file type ie Tday,Tnite,Refl,Elev,Derv,Dt,Inert,Mean",File$
1750  REDIM X(1500),Y(1500),Z(1500)
1760  Filename$=File$[1,4]&Profile$[1,2]
1770  IF (File$="Tday") OR (File$="Tnite") THEN GOTO 2080
1780  IF (File$="Refl") OR (File$="Elev") THEN GOTO 2080
```

```
1790  IF File$="Derv" THEN GOTO 2080
1800  IF File$="Mean" THEN GOTO 1820
1810  IF (File$="Dt") OR (File$="Inert") THEN GOTO Dt_form
1820 Dt_form: FREAD "Tday"&Profile$[1,2],X(*)
1830  J=X(1)
1840  Dist=X(2)
1850  FREAD "Tnit"&Profile$[1,2],Y(*)
1860  REDIM X(J+2),Y(J+2),Z(J+2)
1870  IF (File$="Dt") OR (File$="Inert") THEN MAT Z=X-Y
1880  IF File$="Mean" THEN MAT Z=X+Y
1890  IF File$="Mean" THEN MAT Z=Z*(.5)
1900  IF (File$="Dt") OR (File$="Mean") THEN GOTO 2110
1910 Inert_form: FREAD "Refl"&Profile$[1,2],X(*)
1920  IF Area$="PRB" THEN GOTO 1950
1930  PRINT "Need to reset alpha,beta coeff at Inert_form"
1940  PAUSE
1950  Alpha=52265.8     ! Powder River Basin Parameters.
1960  Beta=-61744
1970  MAT X=X*(.01)       ! Convert to fractions
1980  FOR L=2 TO J+2
1990  IF Z(L)>0 THEN GOTO 2020
2000   Z(L)=2550
2010   GOTO 2060
2020  Z(L)=(Alpha+Beta*X(L))/Z(L)
2030  IF Z(L)<500 THEN Z(L)=450
2040  IF Z(L)>3000 THEN Z(L)=3000
2050  Dum(2)=Dist  ! Dx increment in km.
2060  NEXT L
2070  GOTO 2110
2080  FREAD Filename$,Z(*)
2090  J=Z(1)
2100  Dist=Z(2)
2110  FOR I=1 TO J
2120  Z(I)=Z(I+2)
2130  X(I)=(I-1)*Dist
2140  NEXT I
2150  REDIM X(J),Z(J)
2160  RETURN
2170  !
2180  !                        *******
2190  !
2200 File_plot: SERIAL  ! IF V=1 THEN REPEAT
2210  IF Enable=1 THEN GOTO File_cont
2220  IF Plotter=0 THEN PLOTTER IS 13,"GRAPHICS"
2230  IF Plotter=0 THEN GRAPHICS
2240  IF Plotter=0 THEN GOTO File_cont
2250  IF V=0 THEN PLOTTER IS 7,5,"9872A"  ! First time
2260 File_cont: BEEP
2270  Dz=5
2280  IF (File$[1,1]="E") OR (File$[1,2]="To") THEN Dz=100
2290  IF File$[1,2]="De" THEN Dz=10
2300  IF File$[1,2]="In" THEN Dz=500
2310  Y$=File$
2320  IF (Y$[1,1]="T") OR (Y$[1,1]="D") THEN Y$=Y$&"(K)"
2330  IF Y$[1,1]="M" THEN Y$="Mean temp(K)"
2340  IF Y$[1,1]="E" THEN Y$=Y$&"(m)"
2350  IF Y$[1,1]="R" THEN Y$=Y$&"(%)"
2360  IF Y$[1,2]="De" THEN Y$="Gradient(m/km)"
2370  IF Y$[1,2]="Dt" THEN Y$="Temp diff(K)"
2380  IF Y$[1,1]="I" THEN Y$="Inertia(TIU)"
```

```
2390  X$="Distance(km)"
2400  MAT SEARCH Z(*),MAX;Zmax
2410  MAT SEARCH Z(*),MIN;Zmin
2420  Zmin=INT(Zmin/Dz)*Dz
2430  Zmax=(INT(Zmax/Dz)+1)*Dz
2440  Dzs=(Zmax-Zmin)*.125/8.5
2450  Dxs=X(J)*.125/8.5
2460  FOR I=1 TO J
2470  X(I)=(I-1)*Dist
2480  NEXT I
2490  IF Plotter=0 THEN GOTO 2670
2500  DEG
2510  LIMIT 0,400,0,285
2520  LORG 5
2530  CSIZE 2.75
2540  X1=(1.5*25.4-12.5)*100/285
2550  X2=X1+X(J)*100/285     ! Proper scale
2560  Y1=(1.5*25.4+14)*100/285
2570  Y2=Y1+150*100/285
2580  MOVE (X1+X2)*.5,Y1-.5*25.4*100/285
2590  LABEL X$
2600  LDIR 90
2610  MOVE X1-.9*25.4*100/285,(Y1+Y2)*.5
2620  LABEL Y$
2630  LDIR 0
2640  LOCATE X1,X2,Y1,Y2
2650  FRAME
2660  LORG 5
2670  SCALE 0,X(J),Zmin,Zmax
2680  OUTPUT 705;"VS2;"
2690  MOVE 0,Zmax
2700  DRAW X(J),Zmax
2710  DRAW X(J),Zmin
2720  AXES 10,Dz,0,Zmin,10,2
2730  FOR I=1 TO J
2740  IF I=1 THEN MOVE X(1),Z(1)
2750  DRAW X(I),Z(I)
2760  NEXT I
2770  OUTPUT 705;"VN;"
2780  CSIZE 2
2790  LORG 8
2800  FOR Ys=Zmin TO Zmax STEP Dz
2810  MOVE -Dxs,Ys
2820  LABEL VAL$(Ys)
2830  NEXT Ys
2840  LORG 6
2850  FOR W=0 TO X(J) STEP 20
2860  MOVE W,Zmin-Dzs
2870  LABEL VAL$(W)
2880  NEXT W
2890  LORG 5
2900  MOVE X(J)*.5,Zmax-Dzs*2
2910  LABEL "Profile "&Profile$[1,2]&"'"&" "&Area$&" Area"
2920  IF Plotter=0 THEN LABEL "CONT to continue"
2930  IF Plotter=0 THEN PAUSE
2940  PEN 0
2950  IF Plotter=0 THEN EXIT GRAPHICS
2960  IF Plotter=0 THEN GOTO 2990
2970  IF X(J)*25.4>7 THEN OUTPUT 705;"AF;"
2980  IF X(J)*25.4<=7 THEN OUTPUT 705;"AH;"
```

```
2990  INPUT "Enter 0 to END and 1 to plot another profile",V
3000  IF V=1 THEN RETURN
3010  IF Plotter=0 THEN GOTO End1
3020  IF X(J)*25.4>7 THEN OUTPUT 705;"AF;"
3030  IF X(J)*25.4<=7 THEN OUTPUT 705;"AH;"
3040 End1: GOTO Function_keys
3050  !
3060  !          ******************************
3070  !
3080 Feature: GOSUB File_read
3090 Feat: INPUT "Enter feature and approx pixel value",K$,Jp
3100  J1=Jp-12
3110  IF J1<1 THEN J1=1
3120  J2=Jp+12
3130  IF J2>J THEN J2=J
3140  Sp=0
3150  INPUT "Use CONT to list and 1 to plot",Sp
3160  IF Sp=0 THEN GOTO List
3170  REDIM X2(J2-J1+1),Dum(J2-J1+1)
3180  L=0
3190  FOR K=J1 TO J2
3200  L=L+1
3210  X2(L)=K
3220  Dum(L)=Z(K)
3230  NEXT K
3240  Lmax=L
3250  MAT SEARCH Dum(*),MAX;Rmax
3260  MAT SEARCH Dum(*),MIN;Rmin
3270  Dr=Rmax-Rmin
3280 Feature_plot: PLOTTER IS 13,"GRAPHICS"
3290  GRAPHICS
3300  LOCATE 10,100,20,90
3310  SCALE J1,J2,Rmin,Rmax
3320  GRID 1,(Rmax-Rmin)*.1,J1,Rmin
3330  FOR L=1 TO Lmax
3340  IF L=1 THEN MOVE X2(L),Dum(L)
3350  DRAW X2(L),Dum(L)
3360  NEXT L
3370  LORG 6
3380  FOR L=1 TO Lmax STEP 2
3390  MOVE X2(L),Rmin-(Rmax-Rmin)*.05
3400  LABEL VAL$(X2(L))
3410  NEXT L
3420  LORG 4
3430  MOVE (J1+J2)*.5,Rmin-.04*Dr
3440  LABEL File$
3450  MOVE Jp,Rmax+Dr*.02
3460  LABEL K$
3470  LORG 1
3480  MOVE X2(1),Rmax+Dr*.02
3490  LABEL "CONT to continue"
3500  PAUSE
3510  PEN 0
3520  EXIT GRAPHICS
3530  GOTO 3630
3540 List: PRINT SPA(10),"Feature ";K$
3550  Min=1E99
3560  FOR I=J1 TO J2
3570  Min=MIN(Z(I),Min)
3580  NEXT I
```

```
3590  FOR I=J1 TO J2
3600  IF Z(I)<>Min THEN PRINT I,Z(I)
3610  IF Z(I)=Min THEN PRINT I,Z(I)," ***** "
3620  NEXT I
3630  INPUT "Enter 0 to examine other features ; 1 to terminate",T
3640  IF T=0 THEN GOTO Feature
3650  IF T=1 THEN GOTO Function_keys
3660  !
3670  !              ************************
3680  !
3690 Cross_cor: !  PROFL3       To cross correlate profiling data for images.
3700  ! Method: Shift means to 0 and variances to 1
3710  ! Form cross correl sum for varying delays.
3720  ! Take data in 100 pixel sets( See Kmax)
3730  PRINT PAGE
3740 INPUT "Enter function1 ie Tday,Tnite,Refl ....",X$
3750 INPUT "Enter function2 ie Tday,Tnite,Refl ....",Y$
3760  DISP "Cross corellation."
3770  FREAD Y$[1,4]&Profile$[1,2],R(*)
3780  IF (X2(1)=R(1)) AND (X2(2)=R(2)) THEN GOTO 3830
3790  PRINT "Files are not same type - recheck"
3800  PRINT "Length=";X(1),X(2),"Dist=";R(1),R(2)
3810  INPUT "Do you wish to continue anyway ?",Anz$
3820  IF Anz$[1,1]="N" THEN STOP
3830  J=X2(1)
3840  Fdist=X2(2)
3850 Kmax: Kmax=J DIV 100
3860  J=100
3870  PRINTER IS 0
3880  PRINT
3890  PRINT " List of correlation for ";X$;" and ";Y$;" Profile";Profile$
3900  PRINT
3910  FOR K=1 TO Kmax
3920  I1=(K-1)*100+1
3930  I2=I1+J-1
3940  PRINT "From pixel "&VAL$(I1)&" to "&VAL$(I2)
3950  FOR I=I1 TO I2
3960  X(I-I1+1)=X2(I+2)
3970  Y(I-I1+1)=R(I+2)
3980  NEXT I
3990  REDIM X(J),Y(J),Dum(J),Z(J)
4000  Meanx=SUM(X)/J        ! Transform to Mean=0 Dev=1
4010  Meany=SUM(Y)/J
4020  MAT X=(-Meanx)+X
4030  MAT Y=(-Meany)+Y
4040  MAT Dum=X.X
4050  Var=SUM(Dum)/J
4060  MAT X=(1/SQR(Var))*X
4070  MAT Dum=Y.Y
4080  Var=SUM(Dum)/J
4090  MAT Y=(1/SQR(Var))*Y
4100  PRINT
4110  PRINT "   Delay                    ";X$;".";Y$
4120  FOR Delay=-5 TO 5
4130  Sum1=0
4140  FOR I=6 TO J-5
4150  D=I+Delay
4160  Sum1=ABS(X(I)*Y(D))+Sum1
4170 Next: NEXT I
4180  PRINT "     ";Delay,Sum1
```

```
4190  NEXT Delay
4200  NEXT K
4210  PRINTER IS 16
4220  GOTO Function_keys
4230  !
4240  !        ******************************
4250  !
4260 Cross_plot_sngl: !
4270  Plot_count=1
4280  DISP "Cross plotting - single."
4290  INPUT "Select plotter option: 0 CRT , 1 9872S",Plotter
4300  IF Plotter=0 THEN PLOTTER IS 13,"GRAPHICS"
4310  IF Plotter=1 THEN PLOTTER IS 7,5,"9872A"
4320  IF Plotter=1 THEN LIMIT 0,400,0,285
4330 Cross_cont: INPUT "Enter filename for Xaxis ie Tday,Tnite...",X$
4340  INPUT "Enter filename for Yaxis ie Tday,Tnite...",Y$
4350  Fx$=X$[1,2]
4360  Fy$=Y$[1,2]
4370  IF Fx$[1,2]="To" THEN FREAD "Tday"&Profile$[1,2],X(*)
4380  IF Fy$[1,2]="To" THEN FREAD "Tday"&Profile$[1,2],Y(*)
4390  IF Fx$[1,2]="Tn" THEN FREAD "Tnit"&Profile$[1,2],X(*)
4400  IF Fy$[1,2]="Tn" THEN FREAD "Tnit"&Profile$[1,2],Y(*)
4410  IF Fx$[1,2]="Re" THEN FREAD "Refl"&Profile$[1,2],X(*)
4420  IF Fy$[1,2]="Re" THEN FREAD "Refl"&Profile$[1,2],Y(*)
4430  IF Fx$[1,2]="El" THEN FREAD "Elev"&Profile$[1,2],X(*)
4440  IF Fy$[1,2]="El" THEN FREAD "Elev"&Profile$[1,2],Y(*)
4450  IF Fx$[1,2]="De" THEN FREAD "Derv"&Profile$[1,2],X(*)
4460  IF Fy$[1,2]="De" THEN FREAD "Derv"&Profile$[1,2],Y(*)
4470  IF (Fx$[1,2]="In") OR (Fy$[1,2]="In") THEN GOTO Inert_read
4480  IF (Fx$[1,2]="Dt") OR (Fy$[1,4]="Dt") THEN GOTO Dt_read
4490  IF (Fx$[1,2]="Me") OR (Fy$[1,4]="Me") THEN GOTO Dt_read
4500  GOTO Plotting_setup
4510 Inert_read: !
4520  Alpha=52265.8     ! Powder River Basin Parameters.
4530   Beta=-61744
4540  FREAD "Tday"&Profile$[1,2],X2(*)
4550  FREAD "Tnit"&Profile$[1,2],Z(*)
4560  FREAD "Refl"&Profile$[1,2],Dum(*)
4570  REDIM Dum(ROW(2))
4580  MAT Dum=Dum*(.01)       ! Convert Refl to a fraction
4590  MAT X2=X2-Z
4600  MAT X2=X2*(Beta)
4610  MAT X2=X2+(Alpha)
4620  MAT X2=X2/Dum
4630  FOR I=1 TO ROW(X2)
4640  IF X2(I)<1000 THEN X2(I)=1000
4650  IF X2(I)>3000 THEN X2(I)=3000
4660  IF Fx$="In" THEN MAT X=X2
4670  IF Fy$="In" THEN MAT Y=X2
4680  GOTO 4480
4690 Dt_read: FREAD "Tday"&Profile$[1,2],X2(*)
4700  FREAD "Tnit"&Profile$[1,2],Z(*)
4710  IF (Fx$="Dt") OR (Fy$="Dt") THEN MAT X2=X2-Z
4720  IF (Fx$="Me") OR (Fy$="Me") THEN MAT X2=X2+Z
4730  IF (Fx$="Me") OR (Fy$="Me") THEN MAT X2 [illegible]
4740  IF (Fx$="Dt") OR (Fx$="Me") THEN MAT X=
4750  IF (Fy$="Dt") OR (Fy$="Me") THEN MAT Y=
4760  GOTO 4500
4770 Plotting_setup: IF (Fx$<>"In") OR [illegible]$<>"Dt") THEN J=X(1)
4780  IF (Fx$<>"In") OR (Fx$<>"Dt") TH[illegible] X(2)
```

```
4790  IF (Fx$="Tn") OR (Fx$="Dt") THEN J=Z(1)
4800  IF Fx$="Me" THEN J=Z(1)
4810  IF (Fx$="Tn") OR (Fx$="Dt") THEN Dist=Z(2)
4820  IF Fx$="Me" THEN Dist=Z(2)
4830  FOR I=1 TO J
4840  X(I)=X(I+2)
4850  Y(I)=Y(I+2)
4860  NEXT I
4870  REDIM X(J),Y(J),X2(J),Z(J)
4880  Dx=10
4890  Dy=10
4900  IF X$[1,1]="E" THEN Dx=100
4910  IF Y$[1,1]="E" THEN Dy=100
4920  IF X$[1,1]="I" THEN Dx=500
4930  IF Y$[1,1]="I" THEN Dy=500
4940  IF (X$[1,2]="Tn") OR (X$[1,2]="Dt") THEN Dx=5
4950  IF X$[1,2]="Me" THEN Dx=5
4960  IF (Y$[1,2]="Tn") OR (Y$[1,2]="Dt") THEN Dy=5
4970  IF Y$[1,2]="Me" THEN Dy=5
4980  IF X$[1,1]="R" THEN Dx=5
4990  IF Y$[1,1]="R" THEN Dy=5
5000  IF Plotter=0 THEN LOCATE 20,100,10,90
5010  GOSUB Point_plot
5020  CSIZE 2
5030  LORG 5
5040  MOVE (Xmax+Xmin)*.5,Ymax
5050  LABEL "Profile "&Profile$
5060  IF Plotter=0 THEN GOTO 5210
5070  INPUT "Enter 0 to END and 1 to continue plots",Sz
5080  IF Sz=0 THEN GOTO 5160
5090  IF Plot_count=4 THEN GOTO Reset_plot
5100  Plot_count=Plot_count+1  ! Increment plot counter
5110  GOTO Cross_cont
5120 Reset_plot: OUTPUT 705;"AH;"! Next page
5130             OUTPUT 705;"AH;"
5140             Cross_plot=1
5150             GOTO Cross_cont
5160 OUTPUT 705;"AH;"
5170 OUTPUT 705;"AH;"
5180  DISP "FINISHED."
5190  PEN 0
5200  GOTO Function_keys
5210  LORG 2
5220  MOVE Xmin,Ymax+Yr
5230  LABEL "CONT to continue;DUMP GRAPHICS to copy"
5240  PAUSE
5250  PEN 0
5260  EXIT GRAPHICS
5270  INPUT "Enter 0 to continue and 1 to DIGITIZE plotted points",Z8
5280  IF Z8=0 THEN GOTO Function_keys
5290  GRAPHICS
5300 POINTER (Xmin+Xmax)*.5,(Ymin+Ymax)*.5,2
5310  DIGITIZE Xd,Yd    ! Position cursor
5320  MAT Z=X-Xd
5330  MAT Z=Z.Z
5340  MAT X2=Y-Yd
5350  MAT X2=X2.X2
5360  MAT Z=Z+X2
5370  MAT SEARCH Z(*),MIN;Zmin
5380  MAT SEARCH Z(*),LOC(Z(K)=Zmin);K
```

```
5390  MOVE (Xmin+Xmax)*.5,Ymax+Yr
5400  LABEL "Pixel :";VAL$(K);" .Use CONT to continue"
5410  PAUSE
5420  GOTO 5260
5430  !
5440  !        ************************
5450  !
5460 Cross_plot_mult: !          Cross plots of Tday,Tnite,Topo etc.  2/20/81
5470  PRINT PAGE
5480  INPUT "Select plotter option: 0 CRT , 1 9872S",Plotter
5490  DISP "Cross plotting - multiple."
5500 GOSUB Mult_file_read
5510  GOTO Cont_mult
5520 Mult_file_read: !
5530  P$=Profile$[1,2]
5540  IF Area$="PRB" THEN GOTO 5570
5550  PRINT "Need to revise P mapping parms at Pcoeff"
5560  PAUSE
5570 Pcoeff:  Alpha=52285.6    ! Powder River Basin Parameters.
5580   Beta=-61744
5590  FREAD "Tday"&P$,Tday(*)
5600  FREAD "Elev"&P$,Topo(*)
5610  FREAD "Tnit"&P$,Tnite(*)
5620  FREAD "Derv"&P$,Derv(*)
5630  FREAD "Refl"&P$,Refl(*)
5640  Dist=Topo(2)
5650  J=Topo(1)
5660  FOR L=1 TO J
5670  X(L)=(L-1)*Dist
5680  Tday(L)=Tday(L+2)
5690  Tnite(L)=Tnite(L+2)
5700  Topo(L)=Topo(L+2)
5710  Derv(L)=Derv(L+2)
5720  Dt(L)=Tday(L)-Tnite(L)
5730  Mean(L)=(Tday(L)+Tnite(L))/2
5740  Refl(L)=Refl(L+2)*.01        ! Convert to fractions
5750  Inert(L)=(Alpha+Beta*Refl(L))/Dt(L)
5760  IF Inert(L)>2500 THEN Inert(L)=2950
5770  IF Inert(L)<1000 THEN Inert(L)=550
5780  IF Refl(L)>.2 THEN Refl=.245
5790  IF Derv(L)>30 THEN Derv(L)=35
5800  IF Derv(L)<-30 THEN Derv(L)=-35
5810  NEXT L
5820  REDIM Tday(J),Tnite(J),Topo(J),X(J),Y(J),Derv(J),Dt(J),Inert(J),Refl(J),Mean(J)
5830  RETURN
5840 Cont_mult: !
5850  IF Plotter=0 THEN PLOTTER IS 13,"GRAPHICS"
5860  IF Plotter=1 THEN PLOTTER IS 7,5,"9872A"
5870  GRAPHICS
5880  FOR K=1 TO 20
5890  IF K MOD 4=1 THEN LOCATE 10,50,60,90
5900  IF K MOD 4=2 THEN LOCATE 10,50,10,40
5910  IF K MOD 4=3 THEN LOCATE 70,110,60,90
5920  IF K MOD 4=0 THEN LOCATE 70,110,10,40
5930  ON K GOSUB P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12,P13,P14,P15,P16,P17,P18,P19,P20
5940  IF (K MOD 4=0) AND (Plotter=0) THEN PLOTTER IS 13,"GRAPHICS"
5950  IF (K MOD 4=0) AND (Plotter=1) THEN OUTPUT 705;"EC;" ! Enable cutter
5960  IF (K MOD 4=0) AND (Plotter=1) THEN OUTPUT 705;"AF;" ! Adv and cut
5970  NEXT K
5980  IF Plotter=1 THEN OUTPUT 705;"AH;"   ! Adv and cut
```

```
5990  PEN 0
6000  EXIT GRAPHICS
6010  DISP "FINISHED."
6020  GOTO Function_keys
6030 P1: MAT X=Topo    ! Tday vs Elev
6040  MAT Y=Tday
6050  X$="Topo"
6060  Y$="Tday"
6070  Dx=100
6080  Dy=5
6090  GOTO Cont
6100 P2: MAT X=Derv       ! Tday vs Derv
6110  MAT Y=Tday
6120  X$="Derv"
6130  Y$="Tday"
6140  Dx=10
6150  Dy=5
6160  GOTO Cont
6170 P3: MAT X=Refl     ! Tday vs Refl
6180  MAT Y=Tday
6190  X$="Refl"
6200  Y$="Tday"
6210  Dx=.05
6220  Dy=5
6230  GOTO Cont
6240 P6: MAT X=Derv     ! Tnite vs Derv
6250  MAT Y=Tnite
6260  X$="Derv"
6270  Y$="Tnite"
6280  Dx=10
6290  Dy=5
6300  GOTO Cont
6310 P5: MAT X=Topo     ! Tnite vs Topo
6320  MAT Y=Tnite
6330  X$="Topo"
6340  Y$="Tnite"
6350  Dx=100
6360  Dy=5
6370  GOTO Cont
6380 P7: MAT X=Refl    ! Tnite vs Refl
6390  MAT Y=Tnite
6400  X$="Refl"
6410  Y$="Tnite"
6420  Dx=.05
6430  Dy=5
6440  GOTO Cont
6450 P9:  MAT X=Topo    ! Refl vs Topo
6460  MAT Y=Refl
6470  X$="Topo"
6480  Y$="Refl"
6490  Dx=100
6500  Dy=.05
6510  GOTO Cont
6520 P11:  MAT X=Inert  ! Refl vs Inert
6530  MAT Y=Refl
6540  X$="Inert"
6550  Y$="Refl"
6560  Dx=500
6570  Dy=.05
6580  GOTO Cont
```

```
6590 P10:  MAT X=Derv  ! Refl vs Derv
6600  MAT Y=Refl
6610  X$="Derv"
6620  Y$="Refl"
6630  Dx=10
6640  Dy=.05
6650  GOTO Cont
6660 P15: MAT X=Dt   ! Inert vs Dt
6670  MAT Y=Inert
6680  X$="Dt"
6690  Y$="Inert"
6700  Dx=5
6710  Dy=500
6720  GOTO Cont
6730 P13: MAT X=Topo! Inert vs Topo
6740  MAT Y=Inert
6750  X$="Topo"
6760  Y$="Inertia"
6770  Dx=100
6780  Dy=500
6790  GOTO Cont
6800 P14: MAT X=Derv! Inert vs Derv
6810  MAT Y=Inert
6820  X$="Derv"
6830  Y$="Inertia"
6840  Dx=10
6850  Dy=500
6860  GOTO Cont
6870 P17: MAT X=Topo! Dt  vs Elev
6880  MAT Y=Dt
6890  X$="Elev"
6900  Y$="Dt"
6910  Dx=500
6920  Dy=5
6930  GOTO Cont
6940 P18: MAT X=Derv! Dt vs Derv
6950  MAT Y=Dt
6960  X$="Derv"
6970  Y$="Dt"
6980  Dx=10
6990  Dy=5
7000  GOTO Cont
7010 P19: MAT X=Tnite! Tday vs Tnite
7020  MAT Y=Tday
7030  X$="Tnite"
7040  Y$="Tday"
7050  Dx=5
7060  Dy=10
7070  GOTO Cont
7080 P4: !    LABEL
7090 P8: !
7100 P12: !
7110 P16: !
7120 P20: GOTO Plot_label
7130 Cont: !
7140 Point_plot: !
7150  MAT SEARCH X(*),MAX;Xmax
7160  MAT SEARCH Y(*),MAX;Ymax
7170  MAT SEARCH X(*),MIN;Xmin
7180  MAT SEARCH Y(*),MIN;Ymin
```

```
7190  Xmin=INT(Xmin/Dx)*Dx
7200  Xmax=(INT(Xmax/Dx)+1)*Dx
7210  Ymin=INT(Ymin/Dy)*Dy
7220  Ymax=(INT(Ymax/Dy)+1)*Dy
7230  Xr=(Xmax-Xmin)*.05
7240  Yr=(Ymax-Ymin)*.05
7250  IF Plotter=0 THEN GOTO 7540
7260  LORG 5
7270  CSIZE 2
7280  IF Plot_count=1 THEN GOTO Plt_1
7290  IF Plot_count=2 THEN GOTO Plt_2
7300  IF Plot_count=3 THEN GOTO Plt_3
7310 Plt_4: Xset=8.5*25.4
7320  X1=Xset+69.85
7330  X2=X1+3.75*25.4
7340  Y1=158.75
7350  Y2=254
7360  GOTO 7520
7370 Plt_1: X1=69.85
7380  X2=165.1
7390  Y1=38.1
7400  Y2=133.35
7410  GOTO 7520
7420 Plt_2: X1=69.85
7430  X2=165.1
7440  Y1=158.75
7450  Y2=254
7460  GOTO 7520
7470 Plt_3:  Xset=8.5*25.4
7480  X1=Xset+69.85
7490  X2=Xset+165.1
7500  Y1=38.1
7510  Y2=133.35
7520  Zz=100/(11*25.4)
7530  LOCATE X1*Zz,X2*Zz,Y1*Zz,Y2*Zz
7540  SCALE Xmin,Xmax,Ymin,Ymax
7550  AXES Dx,Dy,Xmin,Ymin
7560  LORG 6
7570  MOVE (Xmin+Xmax)/2,Ymin-Yr*1.5
7580  FOR R=1 TO 2
7590  IF R=1 THEN Z$=X$
7600  IF R=2 THEN Z$=Y$
7610  IF Z$[1,1]="M" THEN Z$="Mean temp(K)"
7620  IF Z$[1,1]="T" THEN Z$=Z$&"(K)"
7630  IF Z$[1,2]="Dt" THEN Z$="Temp diff(K)"
7640  IF Z$[1,2]="De" THEN Z$="Gradient(m/km)"
7650  IF Z$[1,2]="El" THEN Z$="Elevation(m)"
7660  IF Z$[1,2]="In" THEN Z$="Inertia(TIU)"
7670  IF Z$[1,2]="Re" THEN Z$="Refl(%)"
7680  IF R=1 THEN X$=Z$
7690  IF R=2 THEN Y$=Z$
7700  NEXT R
7710  LABEL X$
7720  DEG
7730  LDIR 90
7740  LORG 4
7750  MOVE Xmin-Xr*3.5,(Ymin+Ymax)/2
7760  LABEL Y$
7770  LDIR 0
7780  FOR I=1 TO J
```

```
7790  MOVE X(I),Y(I)
7800  LABEL "."
7810  NEXT I
7820  CSIZE 2.2
7830  LORG 6
7840  FOR X=Xmin TO Xmax STEP Dx
7850  MOVE X,Ymin-Yr*.5
7860  LABEL VAL$(X)
7870  NEXT X
7880  LORG 8
7890  FOR Ya=Ymin TO Ymax STEP Dy
7900  MOVE Xmin-Xr*.5,Ya
7910  LABEL VAL$(Ya)
7920  NEXT Ya
7930  CSIZE 3.3
7940  RETURN
7950 Plot_label: !
7960  SCALE 0,1,0,1
7970  LORG 1
7980  MOVE .2,.75
7990  IF Area$="PRB" THEN LABEL "Powder River Basin Area"
8000  IF Area$="CP" THEN LABEL "Cabeza Prieta Area"
8010  MOVE .5,.5
8020  IF Area$="PRB" THEN LABEL "Aug 20,1978"
8030  IF Area$="CP" THEN LABEL "Apr 3-4,1979"
8040  MOVE .5,.25
8050  LABEL "Profile"&Profile$
8060  IF Plotter=0 THEN DUMP GRAPHICS
8070  RETURN
8080  !
8090  !          ***************************
8100  !
8110 Topo_resample: !  To spline-smooth topo data and restore as Elev binary.
8120  ! and Derv binary.
8130  ! Special correction to Dist and for topo interp.
8140  PRINT PAGE
8150  DISP "Topo resample."
8160  FREAD "Tday"&Profile$[1,2],Tday(*)
8170  FREAD "Topo"&Profile$[1,2],Topx(*)
8180  J=Tday(1)
8190  Dist=Tday(2)
8200  K=Topx(1)
8210  Distz=Topx(2)
8220  FOR I=1 TO J
8230  X(I)=(I-1)*Dist    ! Image file
8240  NEXT I
8250  FOR I=1 TO K
8260  Topx(I)=Topx(I+2)
8270  X2(I)=(I-1)*Distz
8280  NEXT I
8290  ! To interpolate topo data
8300  DIM Xb(4,3),Xbtrn(3,4),Dumx(3,3),Inv(3,3),F(4,1),Rum(3,1),G(3,1)
8310  MAT Xb=(1)
8320  Xb(1,1)=((0=Xb(1,2))=Xb(1,3))
8330  Xb(3,1)=4
8340  Xb(3,2)=2
8350  Xb(4,1)=9
8360  Xb(4,2)=3
8370  MAT Xbtrn=TRN(Xb)
8380  MAT Dumx=Xbtrn*Xb
```

```
8390  MAT Inv=INV(Dumx)
8400  Del=Dist/(2*Distz)        ! =D/2
8410  L=1
8420  Imax=INT(Distz*K/Dist)
8430  IF J>Imax THEN J=Imax       ! Truncate all files to Jmax
8440  FOR I=2 TO J-1
8450  IF (X(I)>=X2(L)) AND (X(I)<=X2(L+1)) THEN GOTO Interp
8460  L=L+1
8470  GOTO 8450
8480 Interp: F(1,1)=Topx(L-1)
8490  F(2,1)=Topx(L)
8500  F(3,1)=Topx(L+1)
8510  F(4,1)=Topx(L+2)
8520  MAT Rum=Xotrn*F
8530  MAT G=Inv*Rum
8540  Zb=(I-1)*2*Del-(L-2)
8550  Dum(I)=G(1,1)/3*(Del^2+3*Zb^2)+G(2,1)*Zb+G(3,1)
8560  Derv(I)=2*G(1,1)*Zb+G(2,1)
8570 Nextl: NEXT I
8580  Dum(1)=Topx(1)       ! End points
8590  Dum(J)=Topx(J)
8600  Derv(1)=(Topx(2)-Topx(1))/Distz
8610  Derv(J)=(Topx(J)-Topx(J-1))/Distz
8620  REDIM Dum(J),Derv(J),Z(J)
8630  MAT Z=Dum
8640  REDIM Topo(J+2),Derv(J+2)     ! Store output as binary files.
8650  FOR I=J TO 1 STEP -1
8660  Topo(I+2)=Dum(I)
8670  Derv(I+2)=Derv(I)
8680  NEXT I
8690  Topo(1)=J
8700  Derv(1)=J
8710  Topo(2)=Dist
8720  Derv(2)=Dist
8730  REDIM Topo(J+2),Derv(J+2)
8740  DISP "Storing binary files."
8750  FCREATE "Elev"&Profile$[1,2],52
8760  FCREATE "Derv"&Profile$[1,2],52
8770  FPRINT "Elev"&Profile$[1,2],Topo(*)
8780  FPRINT "Derv"&Profile$[1,2],Derv(*)
8790  DISP "FINISHED"
8800  GOTO Function_keys
8810  !
8820  !         ********************************
8830  !
8840 File_edit:! To edit binary files.
8850  PRINT PAGE
8860  INPUT "Enter File to be edited ie, Tday,Tnite,Refl,Topo...",Filein$
8870  Filename$=Filein$[1,4]&Profile$[1,2]
8880  REDIM Dum(1500)
8890  FREAD Filename$,Dum(*)
8900  J=Dum(1)
8910  Dist=Dum(2)
8920  PRINT Filename$,"  J=";J,"  Dist=";Dist
8930  PRINT LIN(1)
8940  PRINT "Dum(3)=";Dum(3),"Dum("&VAL$(J+2)&")=";Dum(J+2)
8950 Edit_feature: PRINT "PAUSE AT Edit_feature"
8960  PAUSE
8970  Dum(1)=494     ! ********** SPECIAL MOD FOR PRB BB **************.
8980  Dum(2)=.508
```

```
8990   FOR I=1 TO 496! Sp cludge for BB'
9000   Dum(I)=Dum(I+2)
9010   NEXT I
9020   REDIM Dum(496)
9030   BEEP
9040   PAUSE
9050   INPUT "Do you wish to re_store this file ?",A$
9060   IF A$[1,1]<>"Y" THEN GOTO Edit_feature
9070   PURGE Filename$
9080   FCREATE Filename$,52
9090   FPRINT Filename$,Dum(*)
9100   GOTO Function_keys
9110   !
9120   !        ********************************
9130   !
9140 Elev_correct: DISP " Elevation correction."
9150   FREAD "Tday"&Profile$[1,2],Tday(*)
9160   FREAD "Tnit"&Profile$[1,2],Tnite(*)
9170   FREAD "Elev"&Profile$[1,2],Topo(*)
9180   J=Topo(1)
9190   Dist=Topo(2)
9200   L=0
9210   INPUT "Enter starting and ending distances for elev correl",D1,D2
9220   I1=D1/Dist+1
9230   I2=D2/Dist+1
9240   FOR I=I1+2 TO I2+2
9250   L=L+1
9260   X(L)=Tday(I)
9270   Y(L)=Topo(I)
9280   Z(L)=Tnite(I)
9290   X2(L)=(Tday(I)+Tnite(I))/2
9300   NEXT I
9310   REDIM X(L),Y(L),Z(L),X2(L)
9320   CALL Linear(Y(*),X(*),L,Alpha_day,Beta_day,Dev_day)
9330   CALL Linear(Y(*),Z(*),L,Alpha_nite,Beta_nite,Dev_nite)
9340   CALL Linear(Y(*),X2(*),L,Alpha_mean,Beta_mean,Dev_mean)
9350   PRINTER IS 0
9360   FIXED 4
9370   PRINT "Tday= "&VAL$(Alpha_day)&" * Elev + "&VAL$(Beta_day)&" +/- "&VAL$(Dev_day)
9380   PRINT "Tnite= "&VAL$(Alpha_nite)&" * Elev + "&VAL$(Beta_nite)&" +/- "&VAL$(Dev_nite)
9390   PRINT "Tmean= "&VAL$(Alpha_mean)&" * Elev + "&VAL$(Beta_mean)&" +/- "&VAL$(Dev_mean)
9400   PRINT
9410   STANDARD
9420   PRINTER IS 16
9430   PRINT LIN(5)
9440   PRINT "Use CONT to rename Tday and Tnit as Tdt and Tnt "
9450   PRINT "and store elevation correction values in Tday and Tnit."
9460   PAUSE
9470   RENAME "Tday"&Profile$[1,2] TO "Tdy"&Profile$[1,2]
9480   RENAME "Tnit"&Profile$[1,2] TO "Tnt"&Profile$[1,2]
9490 FCREATE "Tday"&Profile$[1,2],52
9500 FCREATE "Tnit"&Profile$[1,2],52
9510   Elev_corr=1      ! Set elevation correction indicator
9520   Alpha=Alpha_mean
9530   FOR I=1 TO J
9540   Tday(I+2)=Tday(I+2)-Alpha*(Topo(I+2)-1400)
9550   Tnite(I+2)=Tnite(I+2)-Alpha*(Topo(I+2)-1400)
9560   NEXT I
9570   FPRINT "Tday"&Profile$[1,2],Tday(*)
9580   FPRINT "Tnit"&Profile$[1,2],Tnite(*)
```

```
9590  PRINTER IS 0
9600  PRINT
9610  PRINT "To restore data files:"
9620  PRINT "PURGE  Tday.. ;RENAME  Tdy.. TO Tday.. "
9630  PRINT "PURGE  Tnit.. ;RENAME  Tnt.. TO Tnit.. "
9640  PRINT
9650  PRINTER IS 16
9660  DISP "FINISHED."
9670  GOTO Function_keys
9680  !
9690  !        ***********************************
9700  !
9710 Report_plot: !
9720  DISP "Report plotting."
9730  SERIAL
9740  PLOTTER IS 7,5,"9872A"
9750  GOSUB Mult_file_read
9760  MAT Refl=Refl*(100)    ! Convert back to %
9770  Dx=25
9780  X$="Distance(km)"
9790  MAT SEARCH X(*),MAX;Xmax
9800  Xmin=0
9810  Dxs=(Xmax-Xmin)*.125/6
9820  DEG
9830  FOR I=1 TO 4! Four sheets
9840  IF I=1 THEN GOTO Plots1
9850  IF I=2 THEN GOTO Plots2
9860  IF I=3 THEN GOTO Plots3
9870  IF I=4 THEN GOTO Plots4
9880 Plots1: MAT Y=Tday
9890  Y$="Temp(K)"
9900  Dy=5
9910  Sp$=" - Day."
9920  MAT Dum=Tnite
9930  D$="Temp(K)"
9940  Doy=5
9950  Sp2$=" - Night."
9960  GOTO 10230
9970 Plots2: MAT Y=Topo
9980  Y$="Elevation(m)"
9990  Dy=100
10000 Sp$=""
10010 MAT Dum=Derv
10020 D$="Gradient(m/km)"
10030 Sp2$=""
10040 Doy=10
10050 GOTO 10230
10060 Plots3:MAT Y=Dt
10070 Y$="Temp(K)"
10080 Dy=5
10090 Sp$=" - Temp diff."
10100 MAT Dum=Mean
10110 D$=Y$
10120 Sp2$=" - Temp mean."
10130 Doy=Dy
10140 GOTO 10230
10150 Plots4:MAT Y=Refl
10160 Y$="Refl(%)"
10170 Dy=5
10180 Sp$=""
```

```
10190 MAT Dum=Inert
10200 Duy=500
10210 D$="Inertia(TIU)"
10220 Sp2$=""
10230 FOR P=1 TO 2
10240 LIMIT 0,400,0,285
10250 LORG 5
10260 CSIZE 2.75
10270 IF P=1 THEN X1=(2*25.4-12.5)*100/285
10280 IF P=2 THEN X1=X1+8.5*25.4*100/285
10290 X2=X1+5.5*25.4*100/285
10300 Y1=(2*25.4+14)*100/285
10310 Y2=Y1+8*25.4*100/285
10320 MOVE X1+3*25.4*100/285,Y1-.5*25.4*100/285
10330 LABEL X$
10340 LDIR 90
10350 MOVE X1-.9*25.4*100/285,Y1+4.25*25.4*100/285
10360 IF P=2 THEN Y$=D$
10370 LABEL Y$
10380 LDIR 0
10390 LOCATE X1,X2,Y1,Y2
10400 FRAME
10410 LORG 5
10420 IF P=2 THEN MAT Y=Dum
10430 IF P=2 THEN Dy=Duy
10440 IF P=2 THEN Sp$=Sp2$
10450 MAT SEARCH Y(*),MAX;Ymax
10460 MAT SEARCH Y(*),MIN;Ymin
10470 Ymin=INT(Ymin/Dy)*Dy
10480 Ymax=(INT(Ymax/Dy)+1)*Dy
10490 Dys=(Ymax-Ymin)*.125/8.5
10500 SCALE Xmin,Xmax,Ymin,Ymax
10510 AXES Dx,Dy,Xmin,Ymin,4,2
10520 OUTPUT 705;"VS2;"
10530 MOVE Xmin,Ymax
10540 DRAW Xmax,Ymax
10550 DRAW Xmax,Ymin
10560 FOR Ic=1 TO J                    ! Draw curve
10570 IF Ic=1 THEN MOVE X(Ic),Y(Ic)
10580 DRAW X(Ic),Y(Ic)
10590 NEXT Ic
10600 OUTPUT 705;"VN;"
10610 CSIZE 2                          ! Label axes
10620 LORG 8
10630 FOR Ys=Ymin TO Ymax STEP Dy
10640 MOVE Xmin-Dxs,Ys
10650 LABEL VAL$(Ys)
10660 NEXT Ys
10670 LORG 6
10680 FOR Xs=Xmin TO Xmax STEP Dx
10690 MOVE Xs,Ymin-Dys
10700 LABEL VAL$(Xs)
10710 NEXT Xs
10720 LORG 5
10730 MOVE (Xmin+Xmax)*.5,Ymax-Dys*2
10740 LABEL "Profile "&Profile$[1,2]&" "&Sp$&" "&Area$&" Area"
10750 PEN 0
10760 NEXT P
10770 OUTPUT 705;"AH;"
10780 OUTPUT 705;"AH;"
```

```
10760 NEXT I
10800 OUTPUT 705;"AH;"
10810 GOTO Function_keys
10820 !
10830 !        ************************************
10840 !
10850 SUB Linear(X(*),Y(*),L,Alpha,Beta,Dev)
10860 ! Fit Y = Alpha*X + Beta +/- Dev
10870 OPTION BASE 1
10880 DIM X1(500,1),Y1(500,1),Xtrns(1,500),D(1,1),R(1,1),F(1,1)
10890 REDIM X1(L,1),Y1(L,1),Xtrns(1,L)
10900 FOR I=1 TO L
10910 X1(I,1)=X(I)
10920 Y1(I,1)=Y(I)
10930 NEXT I
10940 Xmean=SUM(X1)/L
10950 Ymean=SUM(Y1)/L
10960 MAT X1=X1-(Xmean)
10970 MAT Y1=Y1-(Ymean)
10980 MAT Xtrns=TRN(X1)
10990 MAT D=Xtrns*X1
11000 MAT R=INV(D)
11010 MAT D=Xtrns*Y1
11020 MAT F=R*D
11030 Alpha=F(1,1)
11040 Beta=Ymean-Alpha*Xmean
11050 MAT X1=X1+(Xmean)
11060 MAT Y1=Y1+(Ymean)
11070 MAT X1=X1*(Alpha)
11080 MAT X1=X1+(Beta)
11090 MAT X1=X1-Y1
11100 MAT X1=X1.X1
11110 Dev=SQR(SUM(X1)/(L-1))
11120 SUBEND
11130 SUB Fast_hist(X(*),Dx,L,Xupper,Xlower,Xmin,Xmax)
11140 ! Output is Xmin,Xmax
11150 OPTION BASE 1
11160 REDIM X(L)
11170 Xmin=SUM(X)/L DIV Dx*Dx
11180 MAT SEARCH X(*),LOC(>=Xupper);Nupper
11190 Xmax=Xmin+Dx
11200 Max_search:MAT SEARCH X(*),LOC(>Xmax);N
11210 IF N-Nupper<L*.04 THEN Min
11220 Xmax=Xmax+Dx
11230 GOTO Max_search
11240 Min:MAT SEARCH X(*),LOC(<=Xlower);Nlower
11250 Xmin=Xmin-Dx
11260 Min_search:MAT SEARCH X(*),LOC(<Xmin);N
11270 IF N-Nlower<L*.04 THEN Finish
11280 Xmin=Xmin-Dx
11290 GOTO Min_search
11300 Finish:SUBEND
11310 END
```

5.2 REFERENCE MATERIAL