SEMIANNUAL REPORT TO THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Office of Space Science and Applications

(NASA-CR-179728) THEMATIC MAPPER STUDY OF ALASKAN OPHIOLITES Semiannual Report (Cornell Univ.) 16 p CSCL 08B N87-12035

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G3/43 44544

Project NAS5-28739
Thematic Mapper Study of Alaskan Ophiolites

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Research - January 1986 to July 1986:

1. Spectral Correlation of Ambler District and Maiyumerak Mountain basalts -

The combinations of TM bands that best distinguish basalts of the Brooks Range ophiolites have been determined (band combinations 7,3,1; 5,4,2; and 3,2,1 displayed as red, green, and blue). Two spectrally distinct regions, that correspond to two basalts of different age and composition, have been recognized. Both basalts occur in the Ambler District and in the Maiyumerak Mountains. This information is consistent with the interpretation of a nappe origin for the ophiolite allocthons of the western Brooks Range (see attached abstract, Exhibit 1). The spectral differences between the rocks, although consistent, are very small. Exhibit 2 shows mean Digital Number (DN) values for directly illuminated slopes of the two basalts in the Ambler District. The means for the two rocks differ, at most, by only several digital numbers. The difference between the rocks is not apparent in standard contrast-stretched images with the scaling factor determined by the DN range for the entire image; scaling must be determined based only on the DN's from training areas of the two basalts. Other regions of basalt are now being examined with TM data to determine if similar correlations can be recognized and mapped.

2. Major, Trace and Rare Earth Element Analyses of Brooks Range Ophiolite Samples -

Geochemical analyses, including major, trace, and rare earth elements (REE), are being done in order to study the significance of TM spectral variations that have been observed within some of the sampled rock units. Lithologically homogeneous basalt in the Angayucham Range, southern Brooks Range, has been found to be comprised of two chemically distinct basalts (Pallister, 1985). Some of the basalts have flat or depleted light-REE patterns (types I and II) and are interpreted to have formed in an oceanic plateau setting. Other basalts have enriched light-REE patterns (type III) and are interpreted to have formed in an ocean island setting. Although the two basalts were not distinguished in the field, they have distinct TM spectral signatures (see #1 above). Basalt in the central part of the Ambler District of the Angayucham Range is characterized by type I and II REE patterns and by lower band 7 and band 1 reflectance, and by greater band 3 reflectance. Basalt on the flank of the Angayucham Range is structurally higher, has greater band 7 and band 1 reflectance and lower band 3 reflectance, and is characterized by type III REE patterns.

The TM spectral variations that are observed in the basalts are not directly attributable to the REE contents of the rocks, but rather to various minerals, produced by weathering, on the surface of the rocks. The mineralogy of the altered surfaces of the basalts may vary due to differences in rock composition or, perhaps, to weathering in different tectonic settings.

Basaltic rocks are exposed in the Maiyumerak Mountains, approximately 130 km north of the Angayucham Range; their age and origin is poorly understood. These Maiyumerak basalts exhibit spectral variations that are similar to those exhibited by basalts exposed in the Angayucham Range, and comprise two distinct TM spectral units. Basalt in the core of the Maiyumerak Mountains is characterized by lower band 1 and 7 reflectance and by greater band 3 reflectance, relative to basalt exposed on the margin of the mountain range. We analyzed basalt from the core of the Maiyumerak Mountains; it is characterized by flat REE patterns. These basalts are both chemically and spectrally similar to the type I and II basalts in the Angayuchum Range. Basalt from the margins of the Maiyumerak Mountains is spectrally similar to the type III basalts in the Angayucham Range; chemical analyses of these basalts are in progress. We are beginning a study to determine the mineral compositions of the weathered rock surfaces, using X-ray diffraction. This study might provide information about the observed TM spectral variations.

3. We have examined TM, digital aeromagnetic, and digital elevation data to determine what rock types can be differentiated within the Josephine peridotite, northern California and southwestern Oregon. We are using this area to test the capabilities of the data because the distribution of rocks within the peridotite is well known (we have been studying the Josephine peridotite for the past ten years). Knowledge gained from this test study will be used to constrain our interpretation of less accessible peridotite exposures in the Brooks Range. With the TM data, we have differentiated relatively unhyrdated ultramafic rocks (primarily harzburgite) from hydrated rocks derived from the harzburgite (serpentinite). TM Digital Numbers (means from directly illuminated slopes) for several rock types within the peridotite are shown in Exhibit 3. The spectra differ primarily due to differences in vegetation cover; the serpentinite is very sparsely vegetated and the harzburgite is moderately vegetated (local diorite has a closed vegetation canopy). Within areas of serpentinite, two rock types are differentiated using bands 1,3,7 displayed as red, green, blue; sheared serpentinite, occuring along faults, and bastite serpentinite, where the peridotite is hydrated but not deformed (serpentinite spectra are shown in Exhibit 4). Variations are also recognized within the harzburgite due to variations in vegetation density; vegetation is generally sparse on ultramafic rock due to high Mg to Ca ratios (excess Mg blocks Ca uptake), but anomalously dense vegetation occurs in the south-east part of the peridotite. The peridotite in this area may be lherzolite, which contains a greater amount of Ca-bearing clinopyroxene. Laterite soils, some of which are currently being mined, are also distinguished with the TM data. Field work is being done during August in association with workers from SUNY Albany to further correlate the spectral differences with lithologic differences.

The Josphine peridotite is characterized by a high aeromagnitc anomaly with numerous short wavelength, large amplitude variations. The aeromagentic data is, in general, correlated with topography, so that most of the short wavelength variations are caused by relief. Some large amplitude anomalies, however, are not correlated with elevation. We have applied a principal component transformation to registered digital aeromagentic and elevation data, to extract the component of the aeromagnetic data which is not correlated with topography (the second principal component, 2nd PC). The 2nd PC reveals that the peridotite is an eastward thickening sheet, and that uncorrelated, high amplitude aeromagnetic anomalies occur over exposoures of serpentinite (attributed to the large amount of magnetite produced by serpentinization). Other uncorrelated, very large amplitude anomalies, that are circular and very localized, are not associated with known areas of serpentinite. The source of these anomalies will be investigated in the field during August.

4. Analysis of Geomorphic Provinces from Digital Topography Image -

We have constructed an image of the topography of the western Brooks Range and Colville Basin from individual 1° x 1° blocks of elevation data, and transformed the image to a UTM projection. Previously unrecognized geomorphic provinces in the Colville Basin, north of the Brooks Range, are related to the tectonics of the basin and include: (A) Zagros-style, folded Early and Middle (?) Cretaceous strata unconformably overlain by (B) relatively undeformed, Late (?) Cretaceous strata. The unconformity between (A) and (B) was identified from a TM image. The unconformity, which can be mapped regionally in the topography image, is broadly warped, defining an uplift pattern for the basin. (A) and (B) occur south of an arcuate boundary that separates an uplifted region from (C) a coastal plain with a northward drainage system. Small, elongate, topographically high, and internally-drained basins occur along this arcuate boundary. The basins might be a geomorphic expression of the individual, uplifted fault blocks.

Elevation data for the rest of northern Alaska are being acquired to expand the area covered by the topography image.

5. Analysis of the Lower Noatak River Basin -

The topographic image, regional gravity, TM images, aerial photographs and field mapping suggest that this basin originated as a tectonic basin and that its shape has been modified by glaciation. Analysis of the topographic image indicates that the modern shape of the basin was produced by a glacier lobe that extended south from a number of coalescing alpine glaciers. Small continental glaciers, however, do not cause extensive erosion; the basin, which has an average elevation of only 15 m above sea level, could not have originated by glacial erosion. A high-angle fault recognized on TM images and in the field (mapped by USGS workers as the edge of a synform) bounds the basin on the east and could be part of a graben fault system or strike-slip basin fault system. Ophiolites, which occur in the structurally higher allocthons, are juxtaposed across the fault, with sediments from structurally lower allocthons, indicating that the fault has a down-on-the-west component of displacement. The relative motion that is interpreted for the fault is consistent with the formation of the lower Noatak basin. A regional gravity high, coincident with the basin and terminating the east-west trend of the Brooks Range gravity low, could be due to crustal thinning, consistent with basin formation, or to the basin being floored by dense rock (eg. mafic and ultramafic rock of an ophiolite), or both. (However, the gravity data is not isostatically corrected; the gravity high may be due simply to the low elevation of the basin.) The basin is superimposed across the trend of the Brooks Range, analogous to modern tectonic basins in the Himalayan Mountains.

6. Evaluation of crustal shortening across the Brooks Range from balanced cross-sections -

Two balanced cross-sections (one along the eastern margin, the other along the western margin of the Brooks Range) are being constructed, using the techniques of fault-bend and fault-propagation folding (Suppe, 1983; Suppe and Medwedeff, 1984). These are being used to obtain regional shortening estimates for the Brooks Range in an attempt to constrain tectonic models for the evolution of Northern Alaska. Approximately 30% of the eastern cross-section has been constructed and a preliminary version of this cross-section will be presented at the September NASA meeting. TM data is being used to confirm reconnaissance maps and to obtain structural data where no maps exist. We plan to use the stereoscopic technique for TM data to obtain strikes and dips for the construction of the western cross-section, where geologic mapping is particularly sparse.

7. Geophysical Studies -

Along with TM data, we are examing digital topography, seismic reflection profiles, and magnetic and gravity surveys to better understand the evolution of the Colville Basin, north of the Brooks Range. We recently submitted a Geologic Note to the AAPG Bulletin, "Triassic-age Strike-Slip Fault in the Colville Basin, Northern Alaska", that is based on the observation of a flower structure (characteristic of known strike-slip faults) on regional seismic lines of the Umiat Basin in the National Petroleum Reserve, Alaska. This structure has particular significance in terms of the timing (Brooks Range deformation is Late Jurassic to Early Cretaceous) and nature of deformation (the northern margin of Alaska is generally thought to be extensional), and must now be taken into consideration in models of the tectonic evolution of Northern Alaska.

8. Age of Ophiolite Origin and Emplacement -

As part of our study of the Brooks Range ophiolites we are using $^{40}Ar/^{39}Ar$ isotope techniques to determine the ages of the several isolated exposures of the ophiolites, and to constrain the ages of their crystallization and emplacement (see appended abstract, Exhibit 1). Previous determinations of the igneous ages of the ophiolites by K-Ar whole-rock methods are poorly constrained (147-171 Ma), have large errors, and are essentially indistiguishable from the ages of metamorphic rocks within the ophiolites (153-154 Ma). The similarity of the igneous and metamorphic ages is probably largely a consequence of argon mobility in the rocks that were dated. The $^{40}Ar/^{39}Ar$ method has several advantages over the K-Ar whole-rock method. Because it is possible to study the thermal history of individual minerals within a rock using the $^{40}Ar/^{39}Ar$ method, it is possible to overcome some of the limitations caused by the gain or loss of argon by a sample.

Seven samples collected during the 1985 field season have been analyzed for Ar isotopes. The $^{40}Ar/^{39}Ar$ ages of hornblende from gabbro at Asik Mountain indicate that the rocks crystallized at about 177-179 Ma, and are older than was previously suspected. $^{40}Ar/^{39}Ar$ data from metamorphic biotite and hornblende from Avan Hills and Asik Mountain indicate that metamorphism and cooling occurred at about 165-169 Ma. The metamorphic mineral ages probably record the age of thrusting and emplacement of the ophiolites. Collectively, the isotope data indicate that the ophiolites were crystallized and emplaced within about 10 Ma.

9. Stereoscopic Images from TM Data -

We have utilized techniques for producing stereoscopic images from TM data where there is image side-lap (most of the study area - see Exhibit 5). These are being used to obtain structural data (strikes and dips) and to map the ophiolites.

9. Radar Imagery -

We have digitized and registered radar photomosaics to digital topography data for analysis of regional lineament patterns.

10. Processing -

We are continuing to process TM data tapes into the format compatible with our image processing system as the tapes are received. An updated list of data received is included as Exhibit 6.

References Cited -

Pallister, J. S., 1985, Pillow basalts from the Angayucham Range, Alaska, chemistry and tectonic implications [abstract]: Transactions, American Geophysical Union, v. 66, no. 46, p. 1102.

Suppe, J., 1983, Geometry and kinematics of fault-bend folding: American Journal of Science, v. 283, p. 684-721.

Suppe, J., and Medwendeff, P., 1984, Fault-propagation folding [abstract]: Geological Society of America Abstracts with Programs, v. 16, p. 670.

Exhibits -

1. Abstracts to be presented at the 1986 Geological Society of America Annual Meeting, San Antonio, Texas.

2. Mean Digital Numbers of two Ambler District basalts.

3. Mean Digital Numbers of rock types within the Josephine peridotite.

4. Mean Digital Numbers of two serpentinites and laterite within the Josephine peridotite.

5. Map of northern Alaska showing the area of TM coverage (this project - rectangles) and the area covered by stereoscopic TM imagery (this project - stippled pattern).

6. Catalogue of TM data received up to July 15, 1986.

CORRELATION OF ANGAYUCHAM RANGE AND COPTER IGNEOUS SEQUENCE BASALTS IN THE BROOKS RANGE, ALASKA, FROM THEMATIC MAPPER DATA

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We are studying the tectonics of the Brooks Range using Landsat Thematic Mapper (TM) images in combination with field, geochemical, and geophysical data. Sixteen digital TM scenes of 300,000 km^2 have been acquired, from the Alaskan oil pipeline west to the Bering Sea. Data from the images are being used to constrain balanced cross-sections, and to differentiate and map lithologic units.

TM reflectance data support the interpretation that basalt of the Angayucham Range, along the southern margin of the Brooks Range, and basalt of the Copter Igneous Sequence, exposed in several isolated thrust sheets ~200 km to the west, are equivalent. Two spectrally distinct basalts are recognized in both the Ambler District of the Angayucham Range and in the Copter Igneous Sequence exposure in the Maiyumerak Mountains. In both areas a structurally higher basalt has greater band 7 and band 1 reflectance, and lower band 3 reflectance, than the underlying basalt. In the Ambler District, the TM spectral differences correlate with age, rare earth element and trace element differences identified by USGS workers. Differences between the basalts were not identified by the USGS workers in the field or on aerial photographs. In the Maiyumerak Mountains, the TM spectral differences correlate with color and morphological differences we recognized in the field. We are analyzing Maiyumerak Mountain samples to determine if geochemical differences correlate with spectral differences, as in the Angayucham Range.

This project is funded by the NASA program Thematic Mapper Research in the Earth Sciences (#NAS5-28739).

BROOKS RANGE OPHIOLITE CRYSTALLIZATION AND EMPLACEMENT AGES FROM $^{40}Ar/^{39}Ar$ DATA

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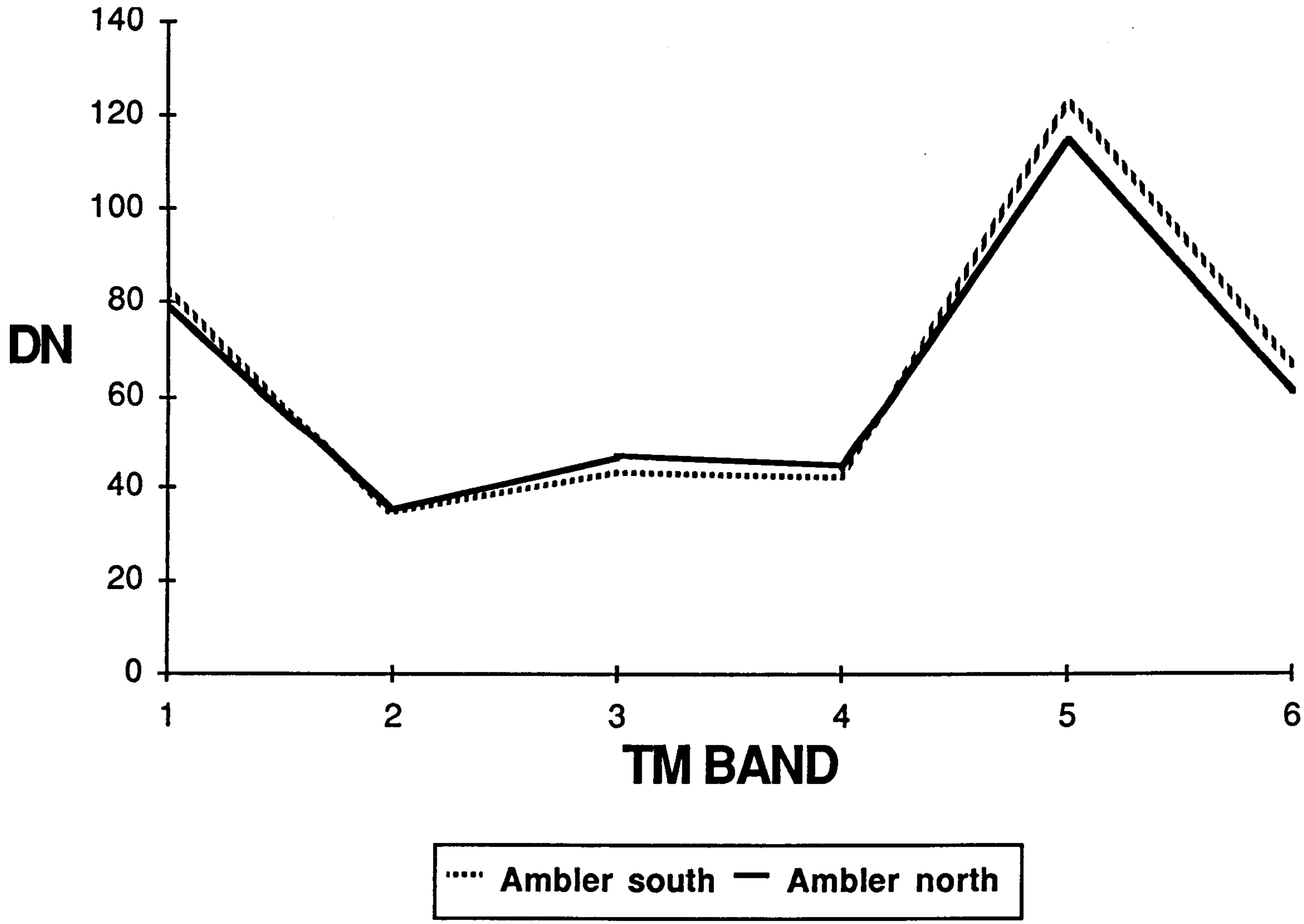
$^{40}Ar/^{39}Ar$ data from hornblende, biotite, and K-feldspar from western Brooks Range ophiolites, northern Alaska, constrain crystallization and emplacement ages. Release spectra from hornblende from two Asik Mountain layered gabbros yield minimum crystallization ages of 177 ± 4 and 179 ± 3 Ma. Release spectra from hornblende and biotite from a thrust fault metamorphic sole between upper, layered, peridotite and gabbro, and lower pillow basalt, at Avan Hills, indicate that metamorphism occurred at 164-169 Ma, the likely age of emplacement. Monzonite within the metamorphic sole yields plateau ages of 165 ± 1Ma for biotite and 146 ± 1Ma for K-feldspar. The $^{40}Ar^{*}$ diffusive loss profile of the K-feldspar is complex but is compatible with continuous Ar loss until 110 Ma, the age of uplift of the Brooks Range interpreted from previously published K/Ar ages. The release spectra from lineated amphibolite from below the thrust contact at Asik Moutain yields an age of 158 ± 10 Ma, and is consistent with the age of metamorphism and thrusting at Avan Hills.

The metamorphic samples are from some of the structurally highest, and by interpretation oldest, thrusts in the Brooks Range. $^{40}Ar/^{39}Ar$ ages for crystallization of the gabbro and metamorphism during thrusting are each approximately 10 Ma older than previously reported K/Ar ages from other western Brooks Range ophiolites. The minimum time-span between crystallization and thrusting was approximately 10 Ma; other ophiolites are known to have similarly short time-spans between crystallization and emplacement.

This work was done at the SUNY-Albany Ar laboratory under the direction of T. M. Harrison, with the assistance of M. T. Heizler.


DN
140
120
100
80
60
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20
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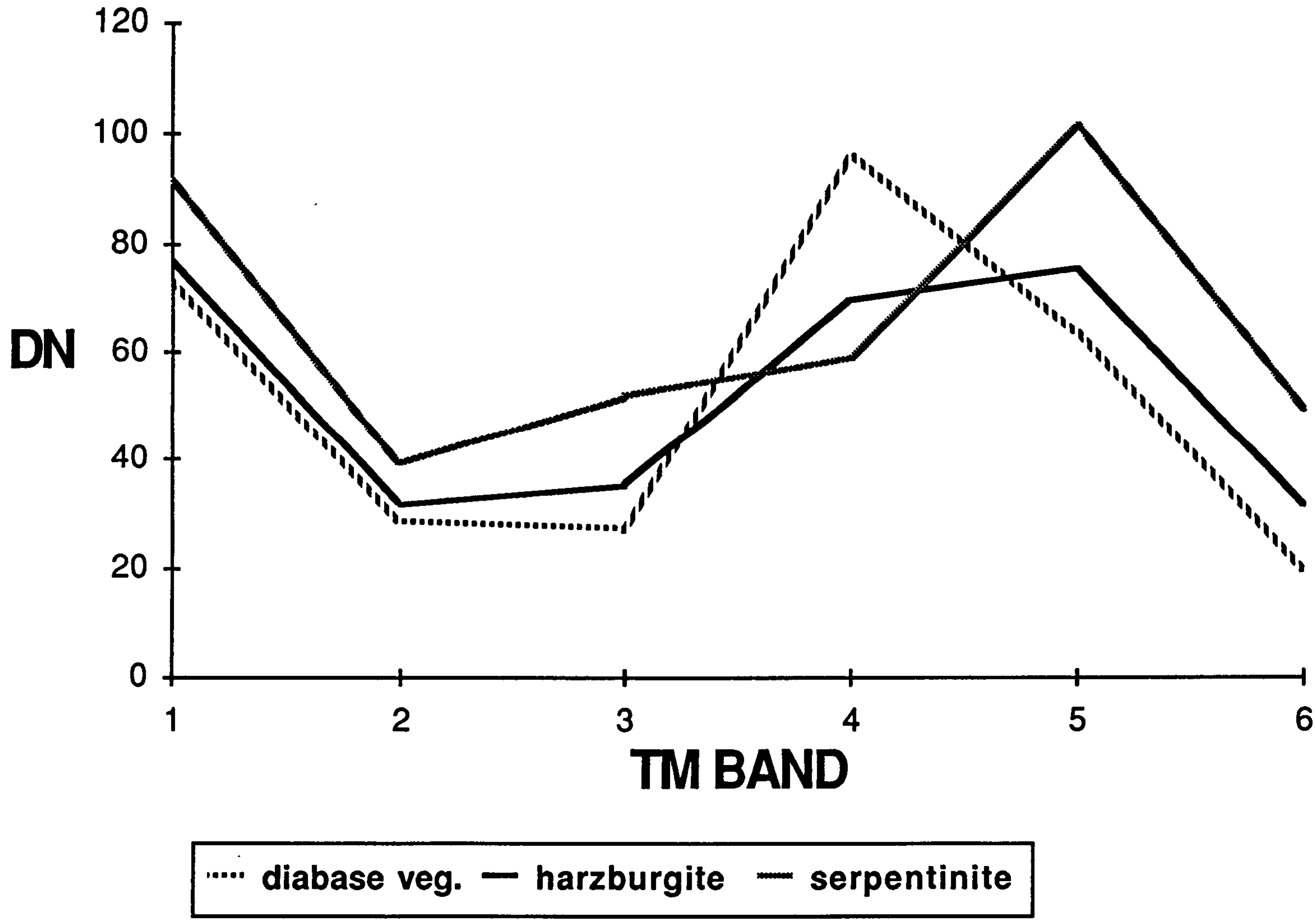
1
2
3
4
5
6
TM BAND
Ambler south
Ambler north

2



120
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DN
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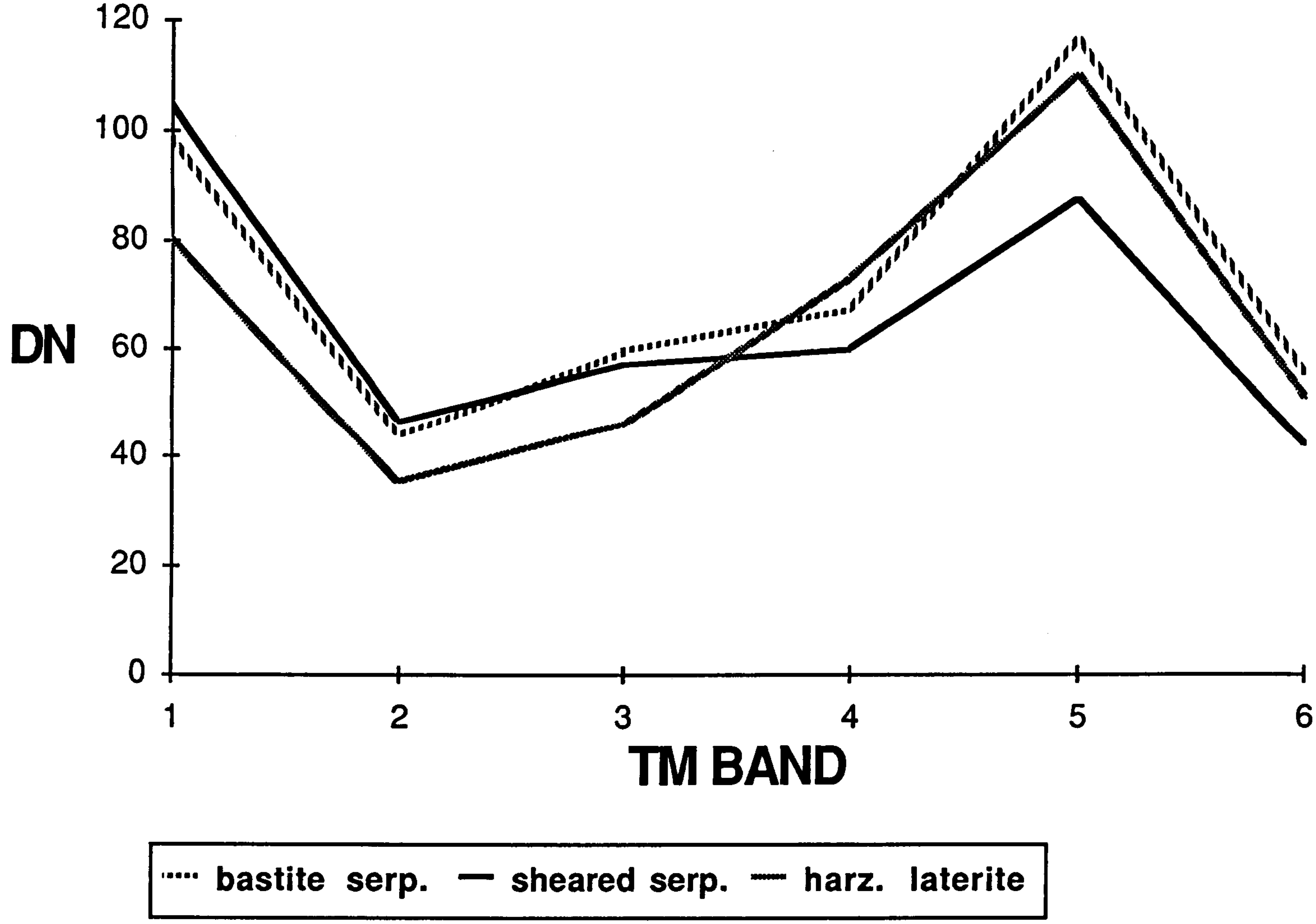
TM BAND
diabase veg.
harzburgite
serpentinite

3



DN
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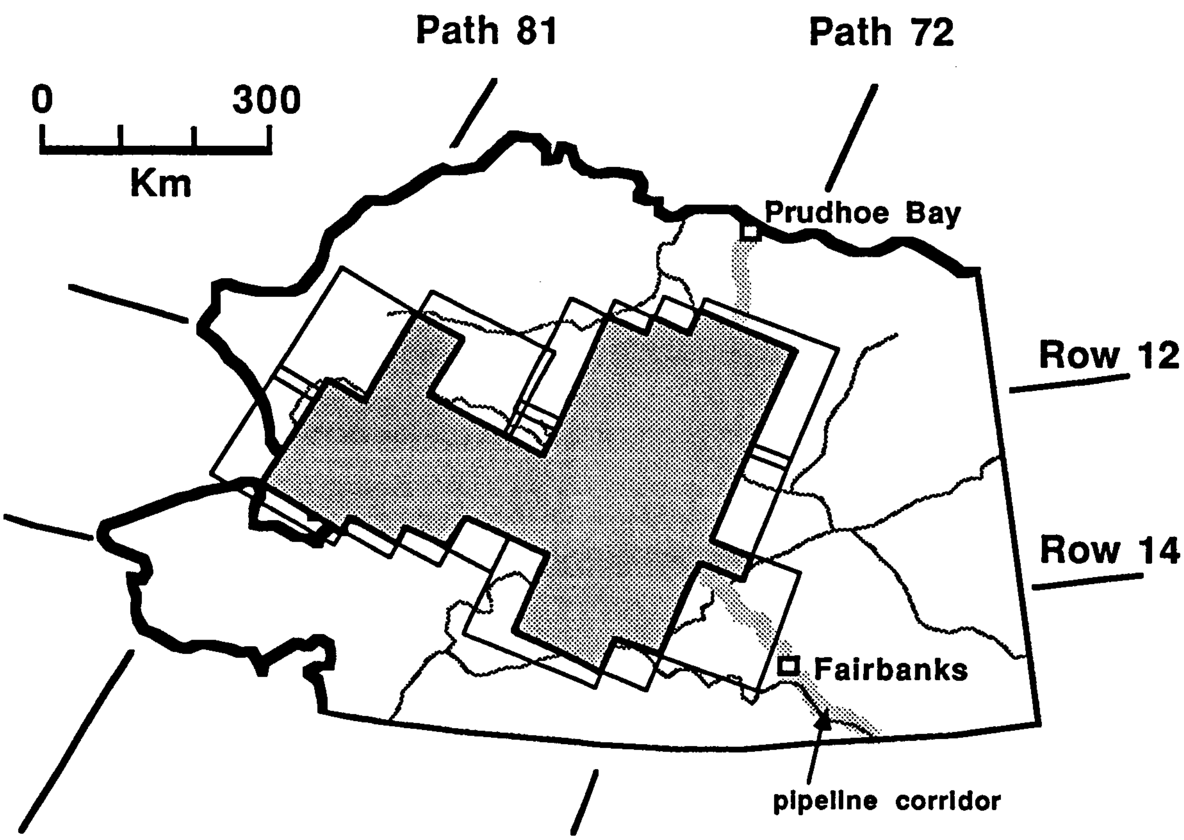
TM BAND
bastite serp.
sheared serp.
harz. laterite

4

STEREOSCOPIC THEMATIC MAPPER COVERAGE



Data Received as of July 15, 1986 -- Dr. J. M. Bird, P.I.

(x) = received (-) = not requested

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046-031	50156018264	840804	X	X	-	-	all 7 bands		
071-014	50507-20545	850721	X	X	X	X	X	X	X
072-012									
072-013	50466-21005	850610	X	X	X	X	X	X	X
072-014									
073-012	50521-21061	850804	X	X	X	X	X	X	X
	50505-21062	850719					X	X	X
073-013	50505-21065	850719					X	X	X
073-014	50521-21070	850804	X	X	X	X			
	50505-21071	850719					X	X	X
074-012	50512-21123	850726	X	X	X	X	X	X	X
074-013	50512-21125	857026	X	X	X	X	X	X	X
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075-012	50503-21184	850717	X	X	X	X	X	X	X
075-013	50503-21191	850717	X	X	X	X	X	X	X
076-012									
076-013									
077-012									
077-013	50517-21312	850731	X	X	X	X	X	X	X
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079-013	50499-21435	850713	X	X	X	X	X	X	X
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