EQUIVALENT LATITUDE (POTENTIAL INSOLATION)

AND

A PERMAFROST ENVIRONMENT:

Caribou-Poker Creeks Research Watershed

Interior Alaska

by

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PREFACE - ACKNOWLEDGEMENTS

This interim report was prepared by Fleetwood R. Koutz, Geologist, Earth Sciences Branch, Research Division, and Charles W. Slaughter, Research Hydrologist, Alaskan Division, USACRREL.

This study attempts to quantify the relationship between the amount of incoming solar radiation and the presence or absence of permafrost on slopes. The study developed from a reading of S. L. Dingman's PhD Thesis on The Hydrology of the Glenn Creek Watershed, Alaska (Dingman, 1970) and subsequent discussions with him. Dr. Dingman calculated "equivalent latitudes" - functions of the slope and aspect relative to the angle of incoming solar radiation - and compared these values to the maximum depth to permafrost during summer and also to different vegetation assemblages in the 0.7 sq. mile watershed. This concept was then applied to Caribou-Poker Creeks Research Watershed of about 40 sq. miles which has succeeded Glenn Creek as the site of most of CRREL's watershed research. The primary result of this effort would be an equivalent-latitude contour map of the watershed that would serve as part of the baseline environmental data for the watershed. This map was constructed during a period of several months and completed in March 1972. In April a preliminary write-up of the project had been completed and plans were made to conduct a validation study of the map in summer 1972 by extensively measuring active-layer thickness. Unfortunately this validation survey was not completed as planned due to higher priorities. However, the map, these results and discussion are included here for future reference.

The authors would especially like to thank Dr. Dingman for his help and encouragement during this project. In addition, the following people are due thanks for their various contributions to the study: J. Brown, R. Haugen, H. McKim, W. Rickard and P. Sellmann. The authors invite comment or criticism of this study. This report is published under the work unit entitled "Cold Regions Terrain and Ecology".

INTRODUCTION

A pressing need exists for comprehensive understanding of environmental systems, especially in the permafrost-dominated landscapes of arctic and subarctic Alaska. Northern planners and managers are facing accelerating pressures on resources and ecosystems, pressures which may cause irreversible and possibly damaging changes to the environment. In many cases planning and utilization have proceeded without information on interrelationships and processes of natural systems which will be affected by these management decisions. Further, basic inventory data on many of these problems does not exist.

The National Environmental Policy Act of 1969 requires that planners and managers consider the probable impact of their proposed actions on the environment. Lack of data and understanding of environmental processes has caused considerable problems for decision makers. A prime example is the continuing furor over the proposed trans-Alaska pipeline.

The most frequent questions raised by "environmentalists" concerning the proposed pipeline deal with the effects of the hot pipe on permafrost supporting the pipe, and possible oil spills resulting from pipe failure due to thawing of underlying permafrost. Possible instability of the subgrade is related to grain size and ice content of the frozen ground. These factors, as well as presence or absence of permafrost must be determined by direct drilling and probing. However, if it were possible to quantitatively predict the occurrence of permafrost in localized areas considerable time and expense might be saved in the planning stages of projects ranging in size from short roads to the trans-Alaska pipeline.

Many workers have noted correspondence between the presence or absence of permafrost and the aspect (orientation) of slopes in the discontinuous permafrost zone, as in central Alaska (e.g., Rieger et al, 1963; Pewe, 1966). Presence of permafrost under north-facing slopes and its absence under south-facing slopes is an accepted generalization. This suggests that the heat balance of the ground is controlled primarily by the amount of incoming solar radiation reaching the ground surface.

Dingman (1970) has developed a method of predicting both the occurrence of permanently frozen ground, and the depth of thaw (active layer thickness*) for the uplands of interior Alaska. Using topographic, thaw depth, and vegetative data, he applied the concept of potential insolation, or equivalent latitude, developed by Lee (1962, 1964) after Kimball (1919), to the 1.8 Km^2 Glenn Creek Watershed in central Alaska.

The following paper applies the concept of equivalent latitude to a much larger and complex area than Glenn Creek (0.7 Mi^2), the Caribou-Poker Creeks Research Watershed (Figure 1), a 40-Mi^2 drainage complex north of Fairbanks, Alaska, at latitude 65.2° N. **

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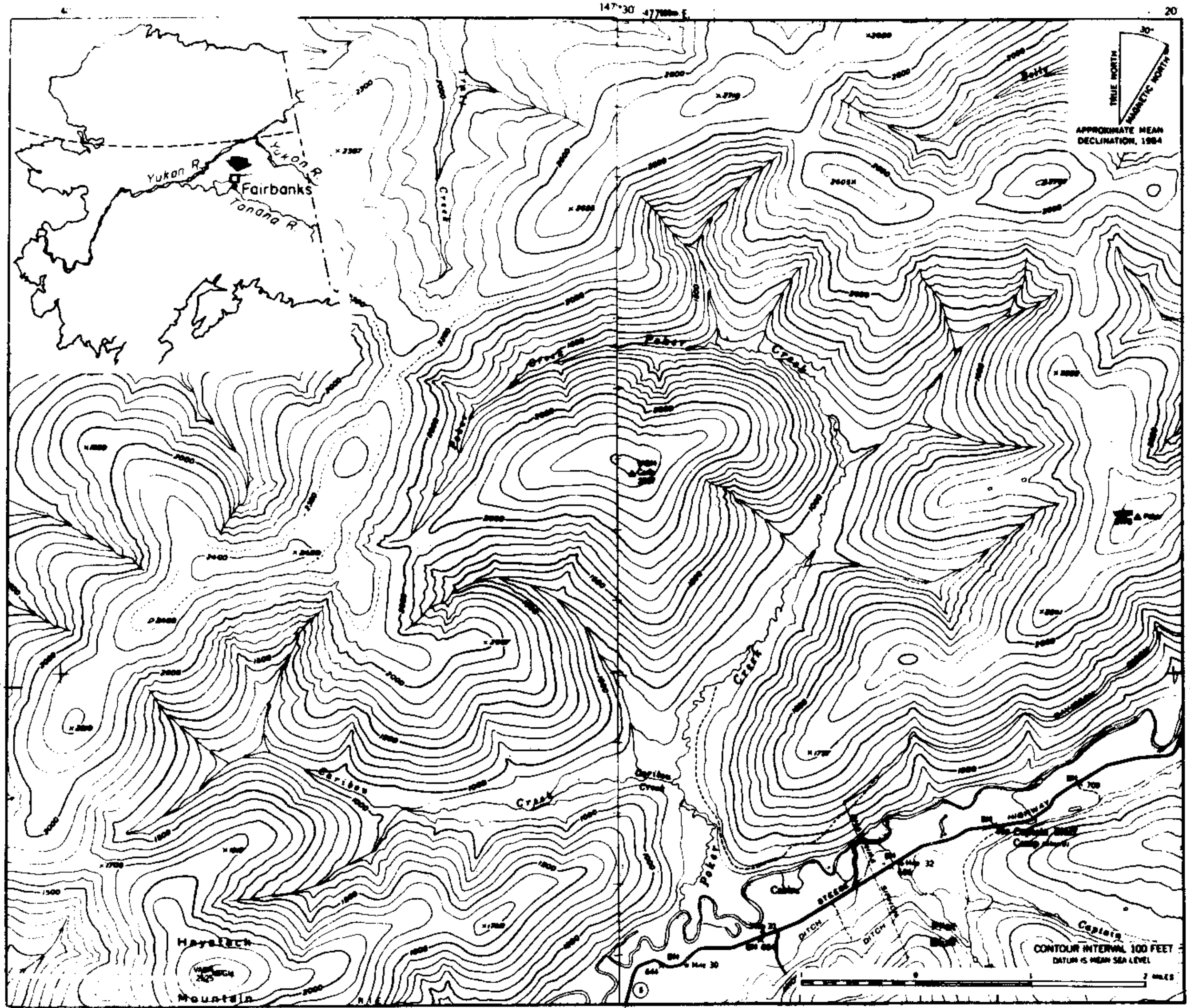
* Zone of seasonal thaw.

** Watershed research is coordinated through the Inter-Agency Technical Committe for Alaska; the project is directed toward a comprehensive inventory and understanding of environmental processes, along with environmental managment experimentation, in a locale considered representative of the permafrost-dominated taiga of the Yukon-Tanana uplands of interior Alaska (Slaughter, 1971).

This report discusses the theory of equivalent latitude and potential insolation; the method of constructing the equivalent latitude map is considered in detail. The correspondence of the map to soils underlain by permafrost and to vegetation and other climatological indices as well as other potential uses of this concept are briefly considered.



CARIBOU-POKER CREEKS RESEARCH WATERSHED
Tanana River Basin, Alaska

Figure 1. Location and topographic map of Caribou-Poker Creeks Research Watershed.

POTENTIAL INSOLATION AND EQUIVALENT LATITUDE

The following discussion is adapted from Dingman and Koutz (1973) and Frank and Lee (1966). It has long been recognized that climatic changes with latitude are largely a function of incoming solar radiation; direct radiation is but one of the important parameters in calculating the energy balance of a natural area. The general relationship for net radiation at a surface can be given as:

$$S = J + H + G - R - A$$

where S = net radiation balance
J = direct beam solar radiation
H = diffuse sky radiation
G = thermal atmospheric
R = reflected
A = geothermal

For long-term averages the last 4 terms largely cancel each other, leaving the net radiation balance primarily dependent on the amount of direct-beam solar radiation.

Neglecting all atmospheric influences (cloud cover, atmospheric attenuation), and topographic and vegetative shading, a theoretical parameter: potential solar beam irradiation or potential insolation can be defined. It is the intensity of the sun's rays on a plane surface, which is proportional to the cosine of the angle of incidence. The latter depends on (1) the latitude, (2) hour-angle (time of day), (3) solar declination (time of year), (4) surface inclination, and (5) surface orientation (azimuth). If specific areas are considered over a long time period (in years), the first 3 factors will be constant and the relative potential insolation will depend on impingement surface inclination and orientation, again neglecting topographic shading (generally unimportant unless topography is steep) and vegetative shading.

Lee (1962, 1964) developed the concept of equivalent latitude as a measure of potential insolation. The concept is based on spherical geometry in that, for every slope on the earth's surface, a horizontal plane tangent to the spherical surface of the earth may be defined which receives the same potential insolation as the sloping plane. Equivalent latitude (θ') depends only on the actual latitude (θ), inclination (k), and aspect or azimuth (h) of the slope; thus:

$$\theta' = \sin^{-1} (\sin k \cdot \cos h \cdot \cos \theta + \cos k \cdot \sin \theta)$$

where "k" is measured as an angle downward from the horizon and "h" as an azimuth angle with respect to true north (Okanoue, 1957). Using a simple computer program (Appendix A) the equivalent latitude table for 65.2° was produced (Appendix B). Values for slope were from 0° to 45° in one-degree increments; values for azimuth were from 0° to 180° on a 5° increment (the equivalent latitude function is symmetrical about a N-S line). The data for several aspects were graphed (Figure 2). This graph shows that for northerly azimuths the equivalent latitude increases with slope up to the point where the equivalent latitude angle plus the slope angle is equal to 90°. At slopes greater than this the equivalent latitude decreases with increasing slope. This may cause conceptual problems in that it appears that the equivalent latitude should increase if a slope were shielded by the bulk of the hill forming the slope

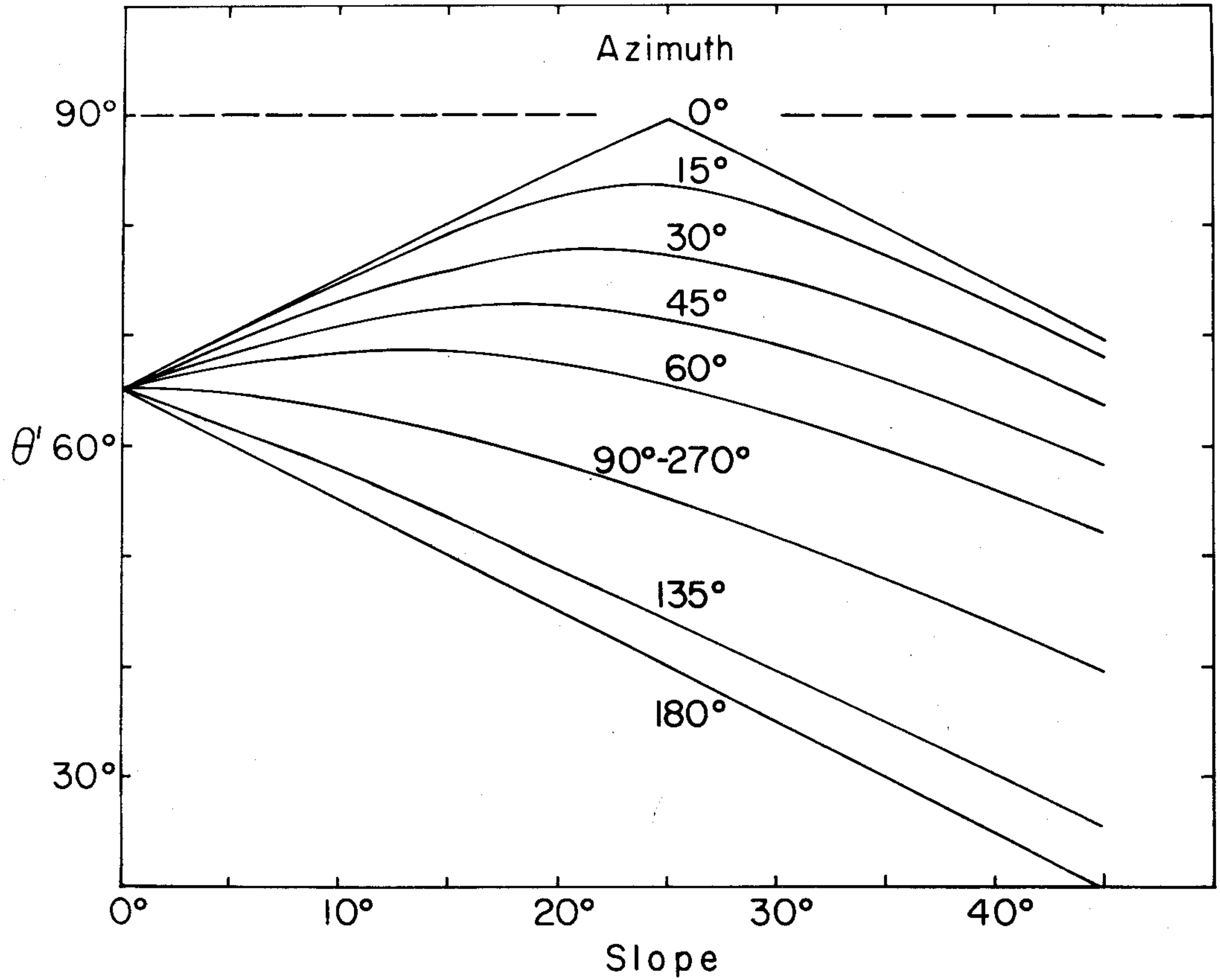


Figure 2. Graph of equivalent latitudes versus slope for various slope-
Data from Appendix B.

(topographic shading). However, this is considering the simplistic model with the <u>average</u> direction of solar radiation directly from the south. In actuality, at high latitudes where the slope - angle plus latitude is greater than 90° for northward-facing slopes, "sunrise" and "sunset" may occur twice within a single 24-hour period (Lee, 1964). This factor ("equivalent longitude") is not significant in the long-term (greater than one year) radiation balance and will not be discussed further here. Frank and Lee (1966) present further discussion of this factor.

Potential insolation is not linearly related to equivalent latitude. Figure 3, from Dingman and Koutz (1973), shows potential insolation (I), expressed as a percentage of the amount received at the equator (3.12×10^5 cal/cm^2 yr), as a function of latitude (List, 1949, Table 133). This curve is approximatly sinusoidal; however, the function is approximately linear from 20° to 70°. Dingman and Koutz found that permafrost thaw depth in the Glenn Creek Watershed showed only slightly better correlation with potential insolation values than did equivalent latitude values. For this reason, in company with constraints of time, a potential insolation map was not constructed for the Caribou-Poker Creeks Research Watershed. It would be a simple matter to construct a potential insolation table and map for the watershed if necessary, but there would be little change of the contour form, especially below 70° equivalent latitude.

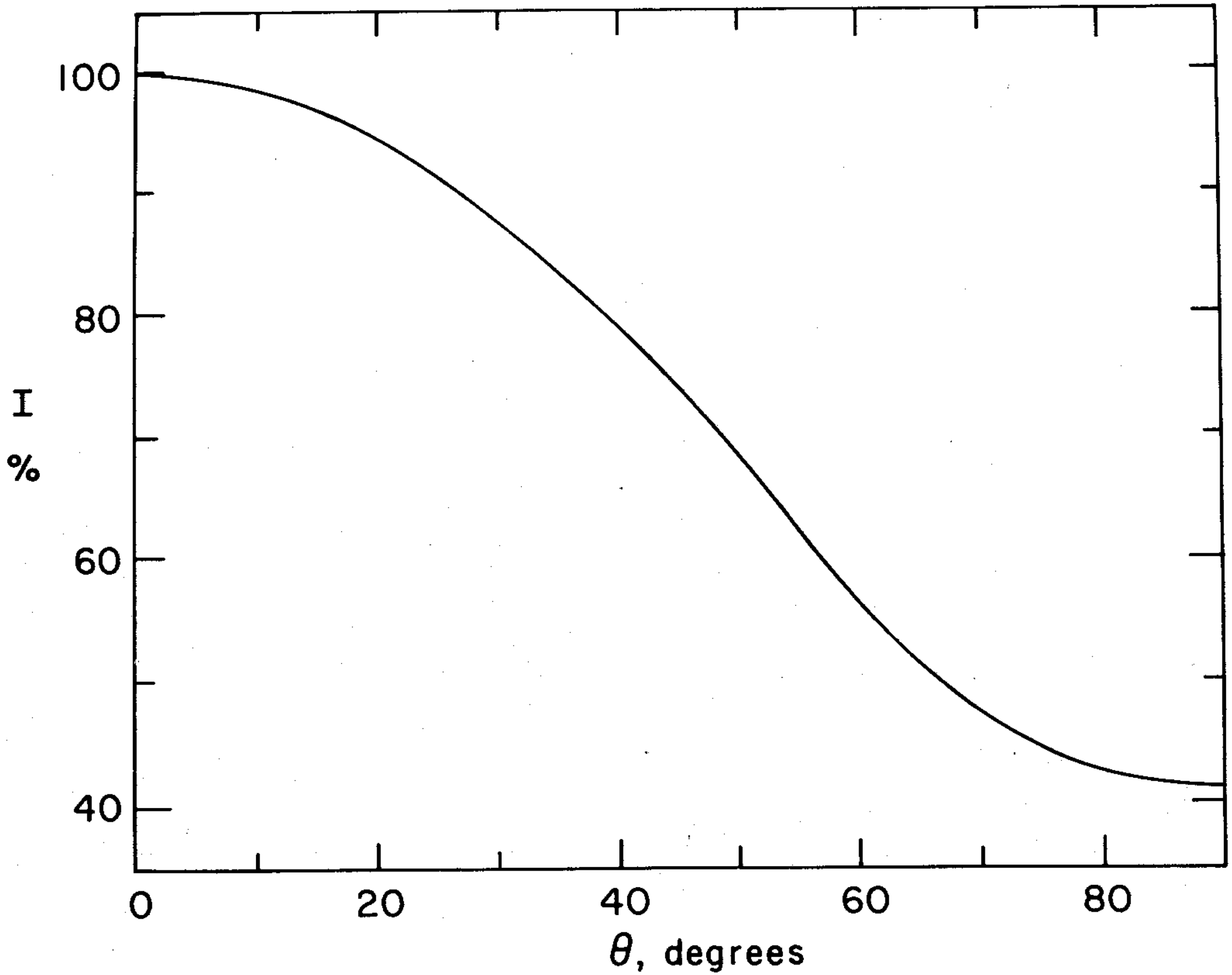


Figure 3. Potential-insolation index, I, expressed as a percentage of potential insolation at the equator, as a function of latitude, θ. From Dingman and Koutz, 1973.

CONSTRUCTION PROCEDURE - EQUIVALENT LATITUDE MAP

The base map used in this study was a 2x enlargement of the northern halves of the U.S. Geological Survey Livengood A1 & A2 (1:63,360) topographic sheets, resulting in a scale of 1" = 0.5 mile or 1:31,580. A N-S, E-W grid was ruled on a mylar overlay on 0.4" (0.2 mile) centers using the NW corner, Sec 6, T3N, R1E as an initial point (on the Fairbanks meridian about 3/4 mile WSW of Haystack Mountain). This grid spacing was chosen so that 2 or 3 contour lines would fall within each grid square over the majority of the map. This spacing was more than adequate for gentle, uniform slopes but was too wide in "rough" portions of the watershed - steep slopes, stream valleys and areas with sinuous contour lines - as will be explained below.

One equivalent latitude value was calculated for each square. The value was plotted in the center of each square, using the grid boundaries as the domain considered in the measurement of the slope and azimuth of the ground surface.

The azimuth of the slope was defined as the direction perpendicular to the average trend of the contour lines within the grid boundary and was measured by protractor to the nearest 5°. Slope was measured along this perpendicular to the nearest 1/50 inch (53 ft), or in some cases the nearest 1/100 inch (26 ft). The horizontal projection of the slope, as represented by contour lines, is actually being determined here; the slope in degrees below the horizontal is evaluated by a simple trigonometric calculation from this horizontal projection. In some cases the grid system presented problems. A single point within the square would not reflect changing slope or azimuth. This was particularly true on ridges and valley bottoms - those areas most critical to a permafrost/non-permafrost boundary. Consequently, in these areas points were taken with smaller domains or with domains "off-center" from the main grid system to provide more information for contouring critical areas.

Streams cutting through a grid square presented a similar problem. This was handled in two ways: (1) the square was divided at the stream and two or more equivalent latitudes were measured - one for each slope on either side of the stream, or (2) the total grid-square was considered and the stream direction and gradient were taken as the azimuth and slope. The first method gave more detailed information for contouring.

The slope and azimuth were recorded on the grid overlay sheet. These data are still available for possible slope-elevation-orientation studies. The equivalent latitude table (Appendix B) was consulted to obtain the correct equivalent latitude value to the nearest 0.1°. This value was recorded on the overlay. Equivalent latitudes for about 1700 points were calculated*. These cover about 66 square miles, about

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* For future reference, the average rate of calculations of slope, aspect, and equivalent latitude was 50 values per hours. This gives a total of 35 hours for all calculations, however the project was conducted over several months. Probably a total of 80 hours or two work-weeks were used in the planning, construction, contouring, and analysis of the equivalent latitude map (Fig. 4).

60% more than the 40.5 square miles included in the drainage area of the watershed proper.

Appendix B was compiled using the computer program shown in Appendix A. The program uses the BASIC language on the Dartmouth Time-Sharing System. The program can be easily modified for any latitude by inserting the new latitude value in line 100. The measurement of slope and aspect is subjective; however, all values obtained are believed to be accurate to ±5° azimuth and 1/50 inch slope. Several dozen points were rechecked periodically during the project and the results found to be reproducible to within the above limits.

After the calculations were complete a clean overlay was prepared with the values rounded to the nearest degree. These data were then hand-contoured to produce isopleths of equivalent latitude, using a 5° contour interval. Nine isopleths resulted, with values from 45° to 85°. While in many areas of the map several interpretations for contouring are possible, all alternatives would yield similar results on a large scale basis. The contours should be accurate to the nearest degree.

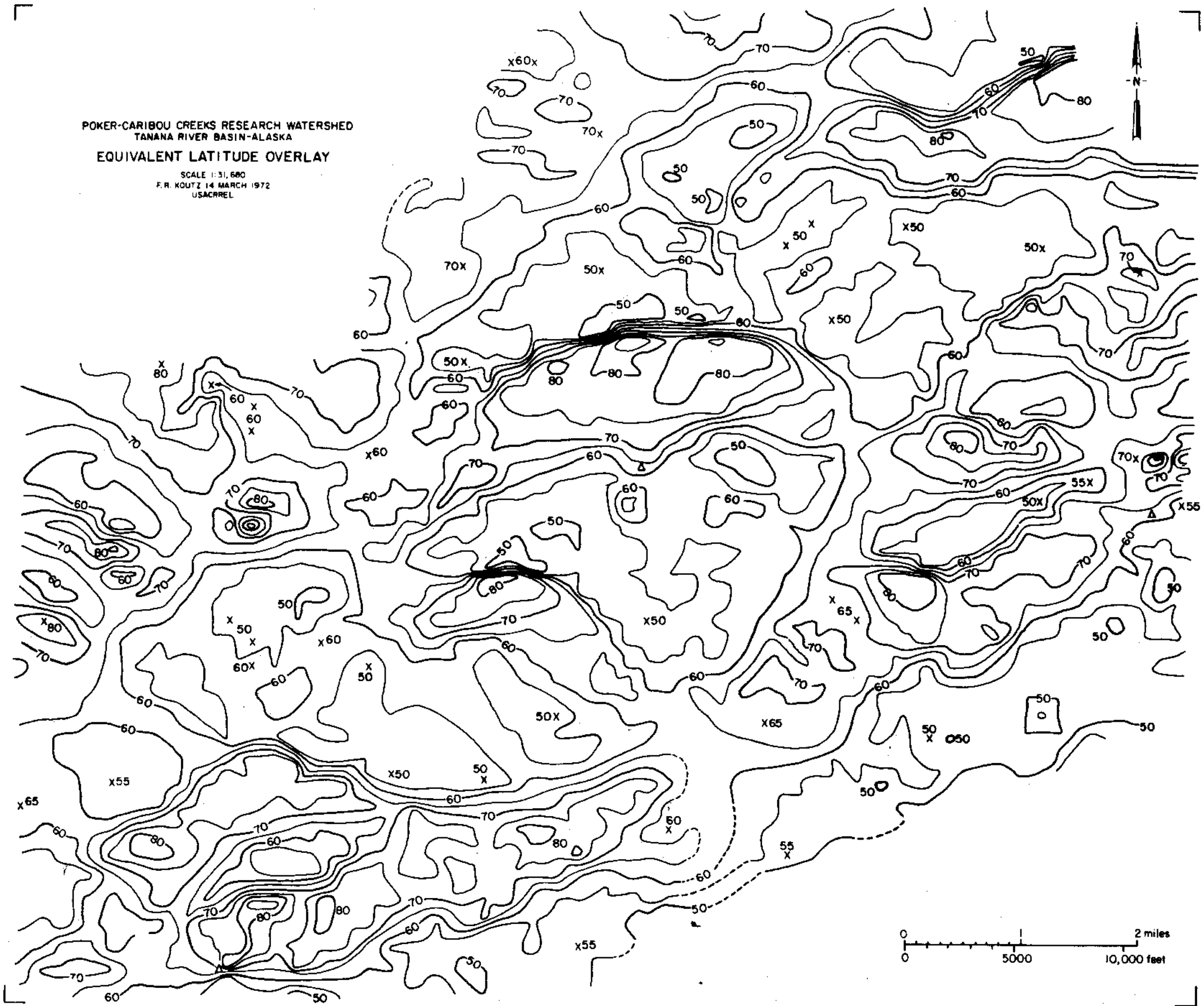

Figure 4. Print of equivalent latitude overlay. Triangles and corner ticks are registry marks corresponding to Figure 1.

RESULTS AND DISCUSSION

The equivalent latitude map is shown in Figure 4*. It is similar in appearance to a topographic contour map, with isopleths concentrated in areas of most rapid change of topographic slope (at slope breaks, valley/wall intersections. Uniform slopes are revealed as large areas of little change in equivalent latitude.

In addition to the topographic map* used to construct this map, several other environmental baseline maps are available for the Caribou-Poker Creeks Research Watershed. A reconnaisance soil survey, (Rieger, _et al_, 1972) and a preliminary vegetation type-map (Vogel and Slaughter, 1972) were completed in 1971. Since these maps were constructed on different air-photo bases it is not possible to directly overlay them with the topographic and equivalent latitude maps**. In addition, field checking of the vegetation map (Troth, _et al_, 1972) has revealed a number of misinterpretations in the type-mapping (which was based solely on air photo interpretation) especially in distinguishing between black and white spruce, which are commonly, although not necessarily correctly, associated with permafrost and non-permafrost landscapes respectively. A small amount of thaw depth data is available (Rickard and Slaughter, 1972) at specific locations as well as considerable reduced but unanalyzed meteorologic and hydrologic data. Several snow courses and a snow

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* These maps are also available as transparent overlays.

** Features mapped on photomosaics that are not planimetrically correct due to parallex are not easily compared in detail to topographic maps and equivalent latitude maps constructed from topographic bases.

pillow have also been operated for the last several years (No radiation data is available). (Slaughter, 1970, 1971, 1972a, 1972b). In addition, Koutz and Slaughter (1972) compiled the background geologic information on the area. Koutz has also spent several days making geologic and other "environmental" observations in the watershed.

Using Figure 4 it is possible to identify areas within the Caribou-Poker Creeks drainage complex which have approximately the same equivalent latitude, and hence are subject to approximately equal radiant heat load on an annual basis.

Accepting equivalent latitude as a valid index of average insolation, and hence of relative "warmth" of a landscape over the long term, two slopes having the same equivalent latitude could be expected to offer similar conditions for temperature-dependent processes such as soil development, vegetation establishment and growth, ground freeze and thaw, and seasonal snowpack ablation, to suggest a few categories. Further, is expected that if environmental conditions (such as air and ground temperatures) in one locale are monitored, results could be extrapolated with reasonable success to nearby areas having the same equivalent latitude.

For instance, the slope on the north side of Haystack Mountain (southwest sector of the basin) has an equivalent latitude of between 70° and 80°, as does a large portion of the slope on the north side of Caribou Peak, near the center of the basin (Figure 1).

Dingman (1970) demonstrated that a close relationship exists between equivalent latitude and presence or absence of permafrost, vegetation assemblages, and thaw depths. He showed that in the elevation range of 840 - 1620 feet for Glenn Creek watershed, the permafrost/non-permafrost boundary lay between the 60° and 65° equivalent latitude isopleth lines. He also calculated that the actual insolation at this boundary was approximately 265 cal/cm^2/day; the potential insolation for 65° N is 440 cal/cm^2/day. Vegetation types corresponded well with these radiation index boundaries. Dingman also suggested that thaw depth would be highly correlated with radiation indices and quantitative measures of moss-ground vegetation thickness and tree-shading.

This similarity in potential energy available at the surface allows the prediction that the local climate, the soils, and the vegetation of these two areas will have some similarity. This can be checked by reference to available vegetation and soils information.

Reiger <u>et al</u>, 1972 mapped 7 soil series in Caribou-Poker Creeks watershed. Each series was separated into independent mapping units based on slope. Four of these series are underlain by permafrost at shallow (less than 3 foot) depth. These four soils, (shaded on Figure 5) the Bradway, Ester, Karshner, and Saulich Silt Loams are primarily located in valley bottoms and on north-facing slopes and cover 26.5% of the watershed. It must be recognized that this is a reconnaisance soil survey and some of the boundaries are more generalized than they would be on a

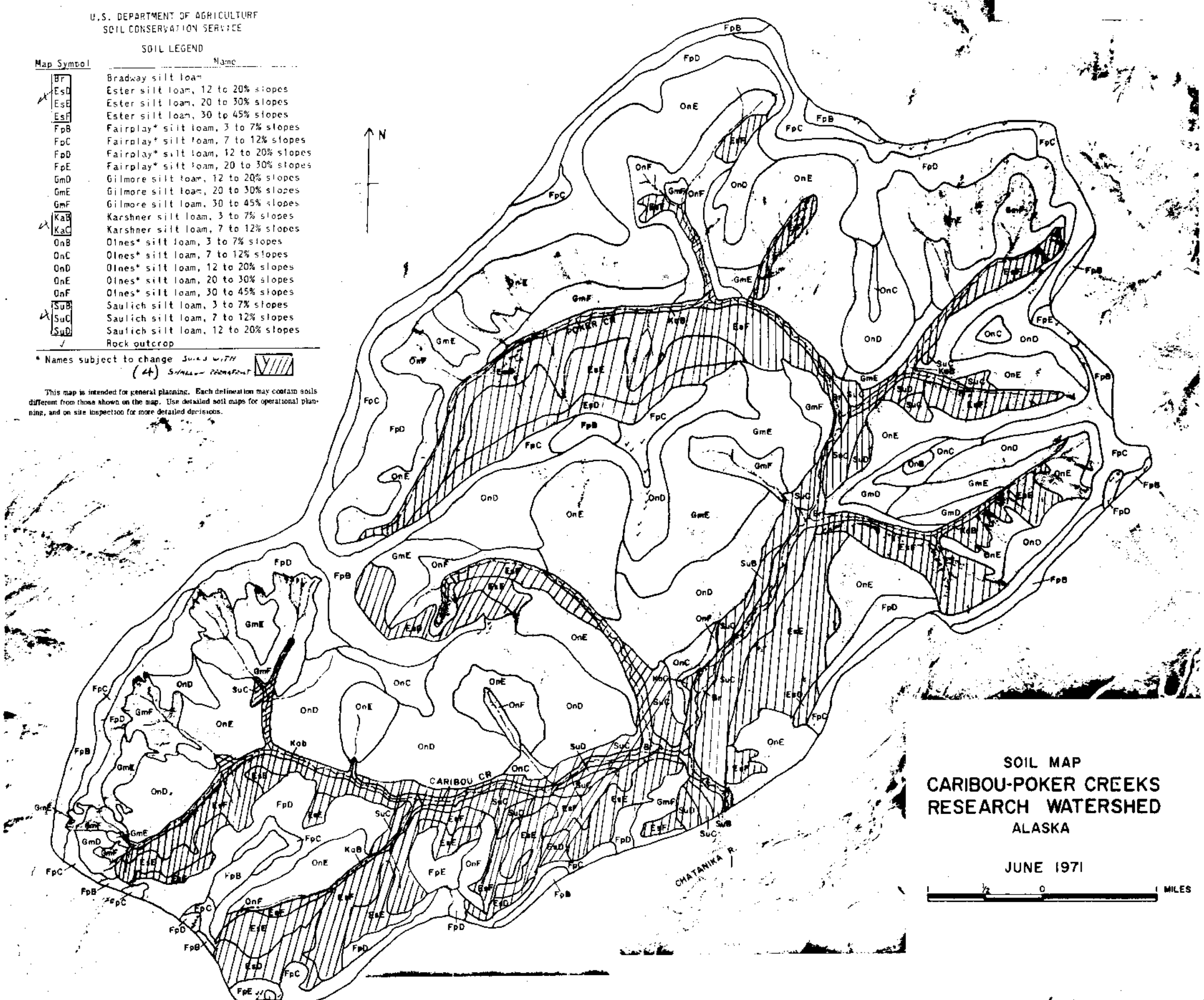

Figure 5. Soils map of Caribou-Poker Creeks Watershed (Rieger, et al, 1972). Soils underlain by shallow permafrost are shaded. This photomosaic is not planimetrically correct.

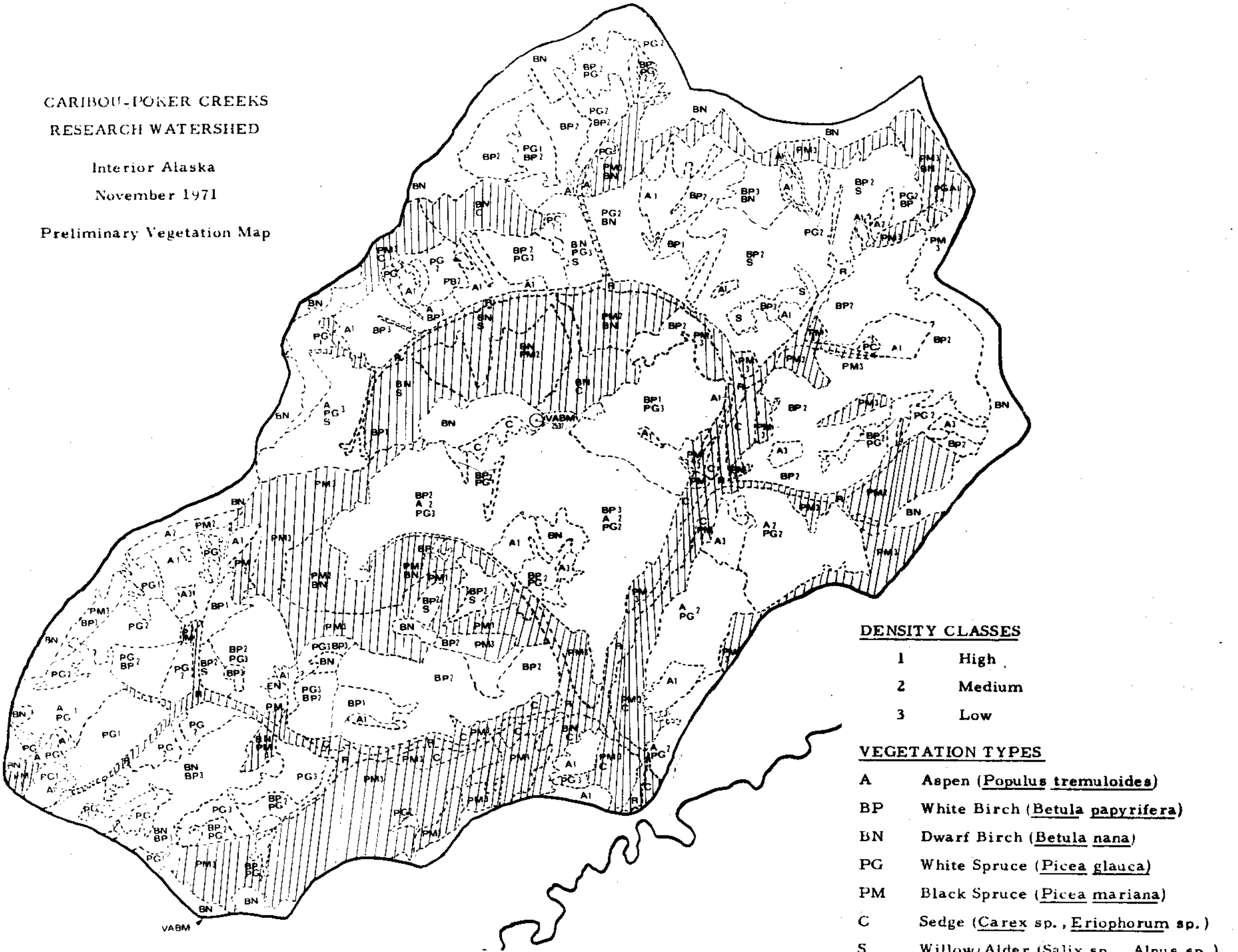

Figure 6. Preliminary vegetation map of Caribou-Poker Creeks Watershed (Vogel and Slaughter, 1972) same photobase as Figure 5.

detailed survey. Rieger et al, also state that these mapping units can contain inclusions of other soils series up to 5 acres in size. Figure 6 shows the preliminary vegetation map (Vogel and Slaughter, 1972) with those vegetation assemblages "usually" associated with near-surface permafrost delineated by Shading. These include the black spruce, sedge, alder/willow and riparian assemblages. The assemblages not "usually" underlain by shallow permafrost include the white spruce, aspen, and white birch types.

A comparison of Figure 5 to Figure 6 reveals several discrepancies in the shaded, permafrost-underlain areas, as, for example, in the "BN-BP_3 and PG_2" areas in the western part of Caribou Creek (C-1). Although these discrepancies exist there is general agreement between the two maps, especially considering that the vegetation map has not been field-checked.

The comparison of vegetation to soils with permafrost and isopleths of equivalent latitude generally corresponds to the findings by Dingman (1970). Riparian and Carex-Black Spruce ecotones in the valley bottoms are underlain by permafrost and lie between the 55° and 70° isopleths of equivalent latitude. The fairly thin Black Spruce (PM_3) and mixed Dwarf Birch and Black Spruce (BN-PM_2) lie above the 60° equivalent latitude isopleth and are associated with permafrost soils. The equivalent latitude for alpine tundra, ridge-top soils and Dwarf Birch vegetation areas varies from 55°-70° (Fairplay soils). Areas dominated by white spruce (PG) are generally below 65° equivalent latitude.

When the soils map is compared with the equivalent latitude map for Caribou-Poker Creeks, a marked correspondence can be found between soils with permafrost and the area above 65° equivalent latitude and soils without permafrost, with equivalent latitude isopleths below 60°.

Figure 7, a compilation of the equivalent latitude map (Fig. 4) and the permafrost-underlain soils map (Fig. 5) shows this very well. By comparing Figures 1 and 4 to 7 and remembering that equivalent latitude is an index of <u>potential</u> insolation and not actual ground temperature (which is the primary factor defining the presence or absence of permafrost) the anomalies between the soil and vegetation types and equivalent latitudes can be accounted for.

For example, most of the Fairplay soils occur in areas of equivalent latitude greater than 65°, especially on the main ridge on the southern boundary of the watershed and Caribou Peak, but only about 5% of this map unit is underlain by permafrost. Several factors may contribute to this phenomena. The Fairplay soils generally occur on high ridges above treeline with a thin organic mat. They probably receive more heat from the sun since the vegetative insulation layer over the mineral soil is thin and there is no tree canopy to limit radiation. Possibly, warm summer winds contribute to increased heating. However, with a lapse rate of about 3.4°F/1000' (Haugen et al, 1971) the ridges should be 4° to 6°F cooler than the valley bottoms if no inversion effects are considered.

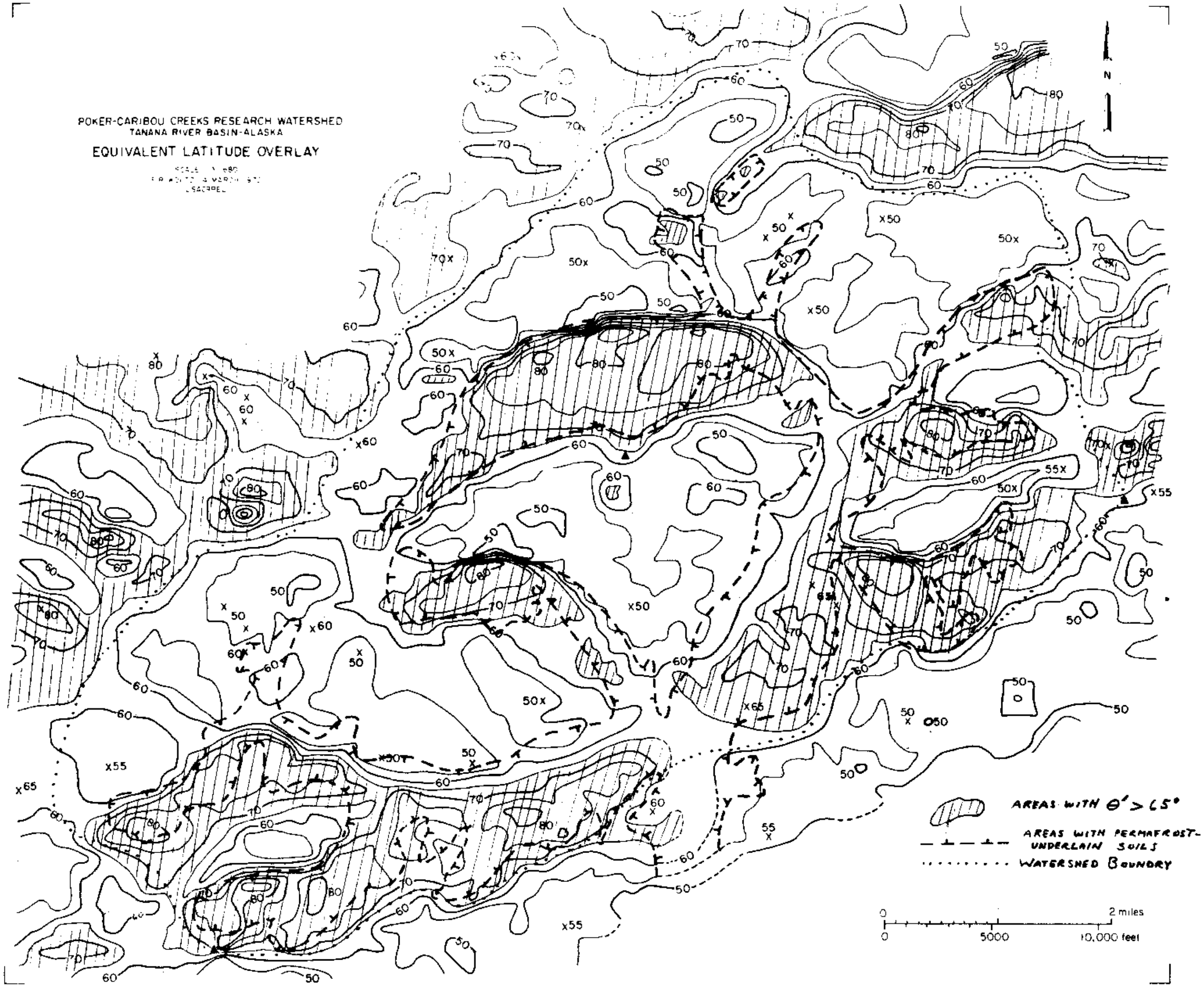

Figure 7. Overlay compilation map showing equivalent latitudes (areas with θ' > 65° are shaded), soil areas within the watershed underlain by permafrost at shallow depth, and watershed boundary. The areas of permafrost - underlain soils were transferred from the photobase (Figure 5) to a topographic intermediate transparency and the soils boundaries approach planimetric correctness.

In the larger valley bottoms of Caribou and Poker Creeks, shallow Karshner and Saulich silt loams (permafrost-underlain) predominate, with an active layer of 40-70 cm as determined by direct probing; yet the calculated equivalent latitude is less than 65° (but greater than 60°) over about 20% of these areas. Topographic shading, a dense vegetative cover (including deep moss carpeting the ground surface), poor drainage in near-level areas, and occasional widespread valley icings (naleds and aufeis - Kane and Slaughter, 1972) may all contribute to this occurrence of permafrost-underlain soils in locales only marginally cold enough according to the calculated equivalent latitude.

During late summer 1972 a limited amount of probing for active-layer thickness was undertaken in the Caribou Creek basin. Much of the area along the trail down from Haystack Mountain into Caribou Creek was found to be underlain by frost-shattered bedrock at a depth of 10-30 cm. Permafrost was found to be extremely sporatic along this trail, generally at 50-60 cm in one or two places. It was absent in the few dozen other places where it was possible to probe between stones. The equivalent latitude along the trail was below 65° over most of its distance.

In the bottom of Caribou Creek Valley (near "Main Site") probing determined that the maximum thaw depth was about 40 to 60 cm. beneath undisturbed sites with the depths generally greater on the south-facing bank of the stream. There were great variations in thaw depth over the stream bottom due to the presence of tussocks and stream channels.

From four probe lines across trails, the "background" thaw in the undisturbed sites runs from 40-70 cm., the average being around 55 to 60 cm. (Rickard and Slaughter, 1972). The equivalent latitude in the valley varies from 60 to 70°. On the north side of the valley (southfacing), the boundary of the permafrost area corresponds closely to the margin of the white spruce - birch forest. Trails in this area show little if any degradation from ground thaw as those in the valley bottom do indicating an absence of permafrost at shallow depth. The equivalent latitude here is about 55°.

As part of an intensive vegetation analysis in portions of the Caribou Creek drainage Troth, et al (in preparation) included measurement of depth to permafrost (if present), elevation, aspect, and slope of eight study sites. From these measurements actual equivalent latitudes were calculated (Table 1). Two sites with equivalent latitudes of 71° and 62° had permafrost at shallow depth, whereas a third had an equivalent latitude of 64° but no permafrost was encountered down to 110 cm. Permafrost was not present at the 5 sites with an equivalent latitude less than 60°. These data do offer support for the contention that an equivalent latitude of 60-65° can be used to approximately divide permafrost from non-permafrost sites.

TABLE 1

Actual Measured Equivalent Latitudes
Caribou Creek Watershed

(Raw data from Troth, *et al*, 1972)

Site No.	Equivalent Latitude (Degrees)	Average Depth to Permafrost
50	59	Absent
51	71	42 cm
52	57	Absent
53	52	Absent
54	55	Absent
55	64	Greater than 110 cm or absent
56	55	Absent
57	62	59 cm

Extensive probing for permafrost as was done by Dingman (1970) at Glenn Creek is not practical over an area the size of Caribou - Poker Creeks Watershed, but the limited probing completed and analysis of the published soils and vegetation map has confirmed that his findings at Glenn Creek can be applied in the larger watershed. Exact correspondence between the watersheds or the overlays can not realistically be expected when it is remembered that (1) the equivalent latitude calculations are based on a topographic map having 100-ft contour intervals, and are calculated on a base grid of 0.2 miles, (2) the soils map and especially the vegetation map are labeled "Reconnaisance", and (3) equivalent latitude is an <u>index</u> of potential insolation, not a measurement of surface temperature or energy status.

Several words of caution in the use of the equivalent latitude concept are also appropriate here. This method should not be used in place of regular engineering-soils/foundation testing methods (e.g. drilling) but only as a tool useful in preliminary planning or as a complement to probing or drilling. This method also only gives an indication of ground temperature, not the ice content or the frost-susceptibility of the materials on slopes. In addition, although the general concept of equivalent latitude/potential insolation can be applied on a world-wide basis for many climatological problems, the specific results obtained here and by Dingman (1970) can only be applied beyond the limited area of the Yukon - Tanana Uplands of Alaska with adequate "ground-truth." For example, by consulting Bates and Bilello (1966) one can see that the 62° latitude line does not separate permafrost areas from non-permafrost areas, particularly in Canada and Siberia.

SUMMARY AND CONCLUSIONS

This project has applied the concept of equivalent latitude/potential insolation as detailed by Dingman (1970) on a much larger scale then has previously been done. It appears, in this preliminary analysis, that there is a close correspondence between this index of solar irradiation and the distribution of permanently frozen ground under specific soil and vegetation types in Caribou-Poker Creeks Research Watershed. This would help confirm the suggestion that permafrost, soils, and vegetation are interrelated, mutually perpetuated results of the radiation balance on slopes.

The results suggest that, with caution, this concept of potential insolation/equivalent latitude can be applied to permafrost/soils/vegetation and climatological studies in general throughout the discontinuous permafrost zone.

With such (presumed) correspondence established for given factors in an area or region, the utility of equivalent latitude calculations as a tool in landscape analysis and a variety of resource management and engineering problems becomes obvious. Data obtained directly from topographic maps becomes a "first cut" denominator of ground - temperature status in the case of the occurrence of permafrost, or potential vegetative cover on various slopes.

Other possible uses could include equivalent latitude analysis to assist in location of weather stations, snow courses, and other data acquisition sites (study sites where the equivalent latitude represents the landscape which is of greatest interest), and locating preferred areas for specific activities such as seasonal snow storage by induced drifting for delayed melt and runoff (e.g., Hendrick, et al, 1971; Slaughter, 1972b).

In all cases, the correspondence of calculated equivalent latitude with the factors or features of concern must be established by objective evaluation; with this caution, widespread utility is seen for this concept in land and resource evaluation planning and management.

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APPENDIX A

Sample Computor Program for Calculating Equivalent Latitudes (BASIC-DTSS)

```
100 LET L = (65.2)  * 3.1416' AVE LATITUDE IN RADIANS
200 FOR A = 0 to 180 STEP 5
250 PRINT " AZIMUTH =   "; A
260 PRINT
270 PRINT "SLOPE", "EQUI-LAT"
300 FOR I = 0 TO 45          'I = SLOPE IN DEGREES
400 LET X = (A/180) * 3.1416     ' CONVERSION TO RADIANTS
500 LET Y = (I/180) * 3.1416
600 LET Z = (SIN(Y) * COS(X) * COS(L)) + COS(Y) * SIN(L))
650 LET Z = Z + 1E-6
700 LET E = ATN(Z/SQR(1-Z↑2)) * (180/3.1416)
1000 PRINT I, E
1010 NEXT I
1020 NEXT A
9999 END
```

Lines 100, 400, 500 & 700 involve converting angular values to and from radians and degrees.

Line 650 prevents division by zero.

Line 700 is the inverse sine function.

Average latitude is 65.2 for the Caribou-Poker Watershed (line 100).

APPENDIX B₁

(270-90)

EQUIVALENT LATITUDES FOR 65.2°N = CARIBOU-POKER CREEKS WATERSHED

SLOPE \ AZIMUTH		0 (EQUI-L)	5/355	10/350	15-345	20/340		25/335	30/330	35/325	40/320	45/315		50/310	55/305	60/300	65/295	70/290		75/285	80/280	85/275	90/270	SLOPE DEGREES
0		65.20	65.20	65.20	65.20	65.20	0	65.20	65.20	65.20	65.20	65.20	0	65.20	65.20	65.20	65.20	65.20	0	65.20	65.20	65.20	65.20	0
1	1/50"	66.20	66.19	66.18	66.16	66.13	1	66.10	66.06	66.01	65.95	65.89	1	65.83	65.76	65.68	65.60	65.52	1	65.44	65.35	65.26	65.18	1
2	44-50	67.20	67.19	67.16	67.12	67.07	2	66.99	66.91	66.81	66.69	66.57	2	66.43	66.29	66.14	65.98	65.81	2	65.64	65.47	65.29	65.12	2
3	31-43	68.20	68.18	68.14	68.08	67.99	3	67.88	67.75	67.59	67.42	67.22	3	67.02	66.79	66.56	66.32	66.07	3	65.81	65.55	65.29	65.03	3
4	25-30	69.20	69.18	69.12	69.03	68.91	4	68.76	68.57	68.36	68.12	67.85	4	67.57	67.27	66.95	66.62	66.28	4	65.94	65.59	65.24	64.89	4
5	20-24	70.20	70.17	70.10	69.99	69.83	5	69.62	69.38	69.11	68.80	68.46	5	68.09	67.71	67.30	66.89	66.46	5	66.03	65.59	65.16	64.73	5
6	17-19	71.20	71.17	71.08	70.93	70.73	6	70.48	70.18	69.83	69.45	69.03	6	68.58	68.11	67.62	67.12	66.60	6	66.08	65.56	65.04	64.52	6
7	15-16	72.20	72.16	72.05	71.87	71.63	7	71.32	70.95	70.54	70.08	69.57	7	69.04	68.48	67.90	67.31	66.70	7	66.09	65.48	64.88	64.29	7
8	13-14	73.20	73.15	73.02	72.81	72.51	8	72.14	71.71	71.22	70.67	70.08	8	69.46	68.81	68.14	67.46	66.76	8	66.07	65.37	64.69	64.01	8
9	12	74.20	74.14	73.99	73.73	73.38	9	72.95	72.44	71.86	71.23	70.56	9	69.84	69.10	68.34	67.56	66.78	9	66.00	65.22	64.46	63.71	9
10	11	75.20	75.13	74.95	74.65	74.24	10	73.73	73.14	72.48	71.76	70.99	10	70.18	69.35	68.49	67.63	66.76	10	65.90	65.04	64.20	63.37	10
11	10	76.20	76.12	75.91	75.55	75.08	11	74.50	73.82	73.06	72.25	71.38	11	70.48	69.55	68.60	67.65	66.70	11	65.75	64.82	63.90	63.01	11
12	9	77.20	77.11	76.86	76.45	75.90	12	75.23	74.46	73.61	72.69	71.73	12	70.73	69.71	68.67	67.63	66.60	12	65.57	64.56	63.57	62.61	12
13	8	78.20	78.10	77.80	77.33	76.69	13	75.93	75.06	74.11	73.09	72.03	13	70.93	69.82	68.69	67.57	66.46	13	65.35	64.27	63.21	62.19	13
14		79.20	79.08	78.73	78.18	77.46	14	76.60	75.62	74.56	73.44	72.28	14	71.09	69.88	68.67	67.47	66.27	14	65.10	63.95	62.83	61.74	14
15	7	80.20	80.06	79.65	79.02	78.19	15	77.22	76.13	74.96	73.74	72.47	15	71.19	69.90	68.61	67.32	66.06	15	64.81	63.59	62.41	61.26	15
16		81.20	81.03	80.56	79.83	78.88	16	77.79	76.59	75.31	73.98	72.62	16	71.24	69.87	68.50	67.14	65.80	16	64.49	63.21	61.96	60.76	16
17	½ - 6/50	82.20	82.00	81.44	80.59	79.53	17	78.31	76.98	75.59	74.16	72.71	17	71.25	69.79	68.34	66.91	65.51	17	64.13	62.79	61.49	60.24	17
18		83.20	82.96	82.30	81.32	80.11	18	78.76	77.31	75.81	74.28	72.74	18	71.20	69.66	68.14	66.65	65.18	18	63.75	62.35	61.00	59.69	18
19		84.20	83.91	83.12	81.98	80.62	19	79.13	77.57	75.97	74.35	72.72	19	71.10	69.49	67.91	66.35	64.82	19	63.33	61.88	60.48	59.12	19
20		85.20	84.84	83.88	82.57	81.05	20	79.43	77.76	76.06	74.35	72.64	20	70.95	69.27	67.63	66.01	64.43	20	62.89	61.39	59.94	58.54	20
21	5/50	86.20	85.73	84.57	83.06	81.39	21	79.64	77.86	76.07	74.28	72.51	21	70.75	69.01	67.31	65.64	64.01	21	62.42	60.87	59.38	57.93	21
22		87.20	86.57	85.15	83.44	81.62	22	79.76	77.89	76.02	74.16	72.32	22	70.50	68.71	66.96	65.24	63.56	22	61.92	60.33	58.80	57.31	22
23		88.20	87.29	85.57	83.68	81.73	23	79.78	77.83	75.89	73.97	72.08	23	70.21	68.37	66.57	64.80	63.08	23	61.40	59.77	58.20	56.67	23
24		89.20	87.78	85.79	83.76	81.73	24	79.71	77.70	75.70	73.73	71.79	24	69.87	67.99	66.14	64.34	62.57	24	60.86	59.19	57.58	56.02	24
25	4/50	89.81	87.88	85.78	83.69	81.61	25	79.54	77.48	75.45	73.43	71.45	25	69.49	67.57	55.69	63.84	62.04	25	60.29	58.59	56.94	55.35	25
26	[Contour interval 100']	88.80	87.54	85.55	83.47	81.37	26	79.28	77.19	75.13	73.08	71.07	26	69.08	67.12	65.20	63.33	61.49	26	59.71	57.97	56.29	54.67	26
27		87.80	86.90	85.11	83.10	81.03	27	78.93	76.84	74.75	72.69	70.64	27	68.62	66.64	64.69	62.78	60.92	27	59.10	57.34	55.63	53.98	27
28		86.80	86.10	84.53	82.62	80.59	28	78.51	76.42	74.32	72.24	70.18	28	68.14	66.13	64.15	62.21	60.32	28	58.48	56.69	54.95	53.27	28
29		85.80	85.23	83.83	82.04	80.08	29	78.03	75.94	73.85	71.75	69.67	29	67.61	65.58	63.59	61.63	59.71	29	57.84	56.02	54.26	52.55	29
30		84.80	84.31	83.07	81.39	79.49	30	77.48	75.41	73.32	71.22	69.14	30	67.06	65.01	63.00	61.02	59.08	30	57.18	55.34	53.55	51.82	30
31		83.80	83.37	82.25	80.67	78.84	31	76.88	74.84	72.76	70.66	68.57	31	66.48	64.42	62.39	60.39	58.43	31	56.51	54.64	52.83	51.08	31
32	3/50	82.8	82.42	81.39	79.91	78.15	32	76.23	74.22	72.16	70.07	67.97	32	65.88	63.80	61.76	59.74	57.76	32	55.82	53.94	52.11	50.33	32
33		81.8	81.45	80.50	79.11	77.42	33	75.55	73.57	71.52	69.44	67.34	33	65.25	63.17	61.11	59.07	57.08	33	55.13	53.22	51.37	49.58	33
34		80.79	80.46	79.60	78.27	76.65	34	74.83	72.88	70.85	68.78	66.69	34	64.60	62.51	60.44	58.39	56.38	34	54.41	52.49	50.62	48.81	34
35	Horizontal projection of slope	79.79	79.50	78.67	77.42	75.85	35	74.08	72.16	70.16	68.11	66.02	35	63.92	61.83	59.75	57.70	55.67	35	53.69	51.75	49.86	48.03	35
36		78.79	78.52	77.74	76.54	75.03	36	73.30	71.42	69.45	67.40	65.33	36	63.23	61.14	59.05	56.99	54.95	36	52.96	51.00	49.10	47.25	36
37		77.79	77.54	76.80	75.65	74.19	37	72.50	70.66	68.71	66.68	64.61	37	62.52	60.43	58.34	56.27	54.22	37	52.21	50.24	48.32	46.46	37
38		76.79	76.55	75.84	74.74	73.33	38	71.69	69.88	67.95	65.94	63.88	38	61.80	59.70	57.61	55.53	53.48	38	51.46	49.48	47.54	45.67	38
39		75.79	75.56	74.89	73.83	72.46	39	70.85	69.07	67.17	65.18	63.14	39	61.06	58.96	56.87	54.78	52.72	39	50.69	48.70	46.75	44.86	39
40		74.79	74.57	73.92	72.90	71.57	40	70.01	68.26	66.38	64.41	62.38	40	60.30	58.21	56.11	54.03	51.96	40	49.92	47.92	45.96	44.05	40
41		73.79	73.58	72.96	71.97	70.68	41	69.14	67.43	65.57	63.62	61.60	41	59.54	57.45	55.35	53.26	51.18	41	49.14	47.12	45.16	43.24	41
42		72.79	72.59	71.99	71.03	69.77	42	68.27	66.58	64.75	62.82	60.81	42	58.76	56.67	54.58	52.48	50.40	42	48.35	46.33	44.35	42.42	42
43	2/50	71.79	71.60	71.01	70.08	68.86	43	67.39	65.73	63.92	62.01	60.01	43	57.97	55.89	53.79	51.70	49.61	43	47.55	45.52	43.53	41.59	43
44		70.79	70.60	70.04	69.13	67.94	44	66.50	64.86	63.08	61.18	59.20	44	57.17	55.09	53.00	50.90	48.82	44	46.75	44.71	42.71	40.76	44
45		69.79	69.61	69.06	68.18	67.01	45	65.60	63.99	62.23	60.35	58.38	45	56.36	54.29	52.20	50.10	48.01	45	45.94	43.89	41.89	39.93	45
AZIMUTH →		0	5/355	10/350	15/345	20/340		25/335	30/330	35/325	40/320	45/315		50/310	55/305	60/300	65/295	70/290		75/285	80/280	85/275	90/270	

F.R. Koutz 4-II-72

APPENDIX B2

(95-265)

EQUIVALENT LATITUDES FOR 65.2°N = CARIBOU-POKER CREEKS WATERSHED

DEGREES SLOPE \ AZIMUTH		95/265	100/260	105/255	110/250	115/245		120/240	125/235	130/230	135/225	140/220		145/215	150/210	155/205	160/200	165/195		170/190	175/185	180	SLOPE
0		65.20	65.20	65.20	65.20	65.20	0	65.20	65.20	65.20	65.20	65.20	0	65.20	65.20	65.20	65.20	65.20	0	65.20	65.20	65.20	0
1		65.09	65.00	64.92	64.84	64.76	1	64.68	64.61	64.54	64.48	64.42	1	64.37	64.32	64.29	64.25	64.23	1	64.21	64.20	64.20	1
2	1/50 44-50	64.95	64.78	64.61	64.45	64.29	2	64.14	64.00	63.87	63.75	63.63	2	63.53	63.45	63.37	63.31	63.26	2	63.22	63.20	63.20	2
3	31-43	64.77	64.51	64.27	64.03	63.79	3	63.58	63.37	63.17	63.00	62.83	3	62.69	62.56	62.45	62.36	62.29	3	62.24	62.21	62.20	3
4	25-30	64.55	64.22	63.89	63.58	63.27	4	62.99	62.72	62.46	62.23	62.02	4	61.83	61.66	61.52	61.41	61.31	4	61.25	61.21	61.20	4
5	20-24	64.30	63.69	63.49	63.10	62.73	5	62.38	62.04	61.74	61.45	61.20	5	60.97	60.76	60.59	60.45	60.34	5	60.26	60.21	60.20	5
6	17-19	64.02	63.53	63.05	62.59	62.16	6	61.74	61.36	61.00	60.66	60.36	6	60.09	59.86	59.66	59.49	59.36	6	59.27	59.21	59.20	6
7	15&16	63.70	63.14	62.59	62.07	61.57	7	61.09	60.65	60.24	59.86	59.52	7	59.22	58.95	58.72	58.53	58.39	7	58.28	58.22	58.20	7
8	13&14	63.36	62.72	62.10	61.51	60.95	8	60.43	59.93	59.47	59.05	58.67	8	58.33	58.03	57.78	57.57	57.41	8	57.29	57.22	57.20	8
9	12	62.98	62.27	61.59	60.94	60.32	9	59.74	59.20	58.69	58.23	57.81	9	57.44	57.11	56.83	56.60	56.43	9	56.30	56.22	56.20	9
10	11	62.57	61.80	61.06	60.35	59.67	10	59.04	58.45	57.90	57.40	56.94	10	56.54	56.19	55.89	55.64	55.45	10	55.31	55.22	55.20	10
11	10	62.14	61.30	60.50	59.73	59.01	11	58.32	57.69	57.10	56.56	56.07	11	55.64	55.26	54.94	54.67	54.46	11	54.31	54.22	54.20	11
12	9	61.68	60.78	59.92	59.10	58.32	12	57.60	56.92	56.29	55.71	55.19	12	54.73	54.33	53.98	53.70	53.48	12	53.32	53.23	53.20	12
13	8	61.19	60.24	59.32	58.45	57.63	13	56.85	56.13	55.47	54.86	54.31	13	53.82	53.39	53.03	52.73	52.50	13	52.33	52.23	52.20	13
14		60.68	59.67	58.71	57.79	56.92	14	56.10	55.34	54.64	54.00	53.42	14	52.91	52.46	52.07	51.76	51.51	14	51.34	51.23	51.20	14
15	7	60.15	59.09	58.07	57.11	56.19	15	55.34	54.54	53.81	53.13	52.53	15	51.99	51.52	51.11	50.78	50.53	15	50.34	50.23	50.20	15
16		59.60	58.48	57.42	56.41	55.46	16	54.56	53.73	52.96	52.26	51.63	16	51.06	50.57	50.15	49.81	49.54	16	49.35	49.23	49.20	16
17		59.02	57.86	56.75	55.70	54.71	17	53.78	52.91	52.11	51.38	50.72	17	50.14	49.63	49.19	48.83	48.56	17	48.36	48.24	48.20	17
18	½ - 6/50	58.43	57.22	56.07	54.98	53.95	18	52.99	52.09	51.26	50.50	49.82	18	49.21	48.68	48.23	47.86	47.57	18	47.36	47.24	47.20	18
19		57.82	56.57	55.38	54.25	53.18	19	52.18	51.25	50.40	49.61	48.91	19	48.28	47.73	47.26	46.88	46.58	19	46.37	46.24	46.20	19
20		57.19	55.90	54.67	53.51	52.41	20	51.37	50.42	49.53	48.72	47.99	20	47.35	46.78	46.30	45.90	45.59	20	45.37	45.24	45.20	20
21	5/50	56.55	55.22	53.95	52.75	51.62	21	50.56	49.57	48.66	47.83	47.08	21	46.41	45.83	45.33	44.92	44.61	21	44.38	44.24	44.20	21
22		55.89	54.52	53.22	51.99	50.82	22	49.73	48.72	47.78	46.93	46.16	22	45.47	44.87	44.36	43.94	43.62	22	43.38	43.24	43.20	22
23		55.21	53.81	52.48	51.22	50.02	23	48.90	47.86	46.90	46.03	45.24	23	44.53	43.92	43.39	42.96	42.63	23	42.39	42.24	42.20	23
24		54.53	53.09	51.73	50.43	49.21	24	48.07	47.00	46.02	45.12	44.31	24	43.59	42.96	42.42	41.98	41.64	24	41.39	41.24	41.20	24
25	4/50	53.83	52.36	50.97	49.64	48.40	25	47.23	46.14	45.13	44.21	43.38	25	42.64	42.00	41.45	41.00	40.65	25	40.40	40.25	40.20	25
26		53.11	51.62	50.20	48.85	47.57	26	46.38	45.27	44.24	43.30	42.45	26	41.70	41.04	40.48	40.02	39.66	26	39.40	39.25	39.20	26
27		52.39	50.87	49.42	48.04	46.74	27	45.53	44.39	43.34	42.39	41.52	27	40.75	40.08	39.51	39.04	38.67	27	38.41	38.25	38.20	27
28	PROJECTION	51.66	50.11	48.63	47.23	45.91	28	44.67	43.51	42.44	41.47	40.59	28	39.80	39.12	38.53	38.05	37.68	28	37.41	37.25	37.20	28
29		50.91	49.34	47.84	46.41	45.07	29	43.81	42.63	41.54	40.55	39.65	29	38.85	38.15	37.56	37.07	36.69	29	36.41	36.25	36.20	29
30		50.16	48.56	47.04	45.59	44.22	30	42.94	41.74	40.64	39.63	38.71	30	37.90	37.19	36.58	36.09	35.70	30	35.42	35.25	35.20	30
31		49.40	47.78	46.23	44.76	43.37	31	42.07	40.85	39.73	38.70	37.77	31	36.95	36.22	35.61	35.10	34.71	31	34.42	34.25	34.20	31
32	3/50	48.63	46.99	45.42	43.93	42.52	32	41.20	39.96	38.82	37.78	36.83	32	35.99	35.26	34.63	34.12	33.72	32	33.43	33.25	33.20	32
33		47.85	46.19	44.60	43.09	41.66	33	40.32	39.07	37.91	36.85	35.89	33	35.04	34.29	33.66	33.13	32.72	33	32.43	32.25	32.20	33
34		47.06	45.38	43.77	42.24	40.80	34	39.44	38.17	36.99	35.92	34.95	34	34.08	33.32	32.68	32.15	31.73	34	31.43	31.25	31.20	34
35		46.27	44.57	42.94	41.40	39.93	35	38.55	37.27	36.08	34.99	34.00	35	33.12	32.36	31.70	31.16	30.74	35	30.44	30.26	30.20	35
36		45.47	43.75	42.11	40.54	39.06	36	37.67	36.36	35.16	34.06	33.06	36	32.17	31.39	30.72	30.18	29.75	36	29.44	29.26	29.20	36
37	HORIZONTAL	44.66	42.93	41.27	39.69	38.19	37	36.78	35.46	34.24	33.12	32.11	37	31.21	30.42	29.74	29.19	28.76	37	28.44	28.26	28.20	37
38	∥ SLOPE	43.85	42.10	40.42	38.83	37.31	38	35.88	34.55	33.32	32.19	31.16	38	30.25	29.45	28.76	28.20	27.76	38	27.45	27.26	27.20	38
39		43.03	41.27	39.57	37.96	36.43	39	34.99	33.64	32.39	31.25	30.21	39	29.29	28.48	27.79	27.22	26.77	39	26.45	26.26	26.20	39
40		42.21	40.43	38.72	37.09	35.55	40	34.09	32.73	31.47	30.31	29.26	40	28.32	27.50	26.81	26.23	25.78	40	25.45	25.26	25.20	40
41		41.38	39.59	37.87	36.22	34.66	41	33.19	31.82	30.54	29.37	28.31	41	27.36	26.53	25.83	25.24	24.79	41	24.46	24.26	24.20	41
42		40.55	38.74	37.01	35.35	33.77	42	32.29	30.90	29.61	28.43	27.36	42	26.40	25.56	24.84	24.25	23.79	42	23.46	23.26	23.20	42
43	2/50	39.71	37.89	36.14	34.47	32.88	43	31.39	29.98	28.68	27.49	26.40	43	25.44	24.59	23.86	23.27	22.80	43	22.46	22.26	22.20	43
44		38.87	37.04	35.28	33.59	31.99	44	30.48	29.06	27.75	26.54	25.45	44	24.47	23.61	22.88	22.28	21.81	44	21.47	21.26	21.20	44
45		38.02	36.18	34.41	32.71	31.10	45	29.57	28.14	26.82	25.60	24.49	45	23.51	22.64	21.90	21.29	20.81	45	20.47	20.26	20.20	45
		95/265	100/260	105/255	110/250	115/245		120/240	125/235	130/230	135/225	140/220		145/215	150/210	155/205	160/200	165/195		170/190	175/185	180	

F.R. KOUTZ: 4/II/72