INSTITUTE of HYDROLOGY

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DETECTING THE OCCURRENCE OF GROUNDWATER USING REMOTELY SENSED DATA - A STUDY IN SE ZIMBABWE

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Introduction

This report describes a brief study to assess the use of remotely sensed data, by recognising indicators of greater groundwater occurrence, to assist the siting of wells. The indicators are based on the presence and nature of vegetation in the areas being investigated. Remotely sensed data is capable uniquely of being analysed to show the spatial changes in these indicators.

Basis of the method

Remotely sensed data consists of measurements of the amount of electromagnetic energy, for selected windows or bands in the electromagnetic spectrum, received at the satellite's sensors. For sensors that operate in the optical part of the electromagnetic spectrum, such as those on Landsat 5, the amount of energy is a function of three main factors. The first is the amount of energy coming from the sun, the illumination source. The second factor is the amount of energy absorbed in its passage through the atmosphere. The third factor is the amount of energy reflected by the earth's surface, i.e. water, soils, vegetation etc. The first two factors are either constant or vary slowly within an image formed by remotely sensed data so that the major source of changes is variations in the amount of energy reflected by the surface materials.

The amount of energy reflected by a surface is a function of wavelength and, in the case of vegetation, it is thought that this can be ascribed to definite physical properties of the vegetation, in particular to the leaf structures. Figure 1 shows some reflection spectra of green vegetation. The strong absorption in the visible portion of the spectra, 400 to 680 nanometres, is due to the presence of chlorophyll and it is this energy that is used by plants for photosynthesis. The comparatively high reflection between 680 and 1000 nanometres was first recognised by Gausmann (1977) as being due to the mesophyll structure of leaves, in particular to the stomata which are used for transpiration. The ratio between the reflectance in the red portion of the spectrum, 630 to 690 nanometres, and that in the near infra-red, 760 to 900 nanometres, has been used in the past as a measure of biomass or Leaf Area Index etc. but is now thought, Sellers (1985) to be more a measure of the transpiration capacity of the vegetation. This ratio, and other similar measures, are known as vegetation indices, Tucker (1979). It can

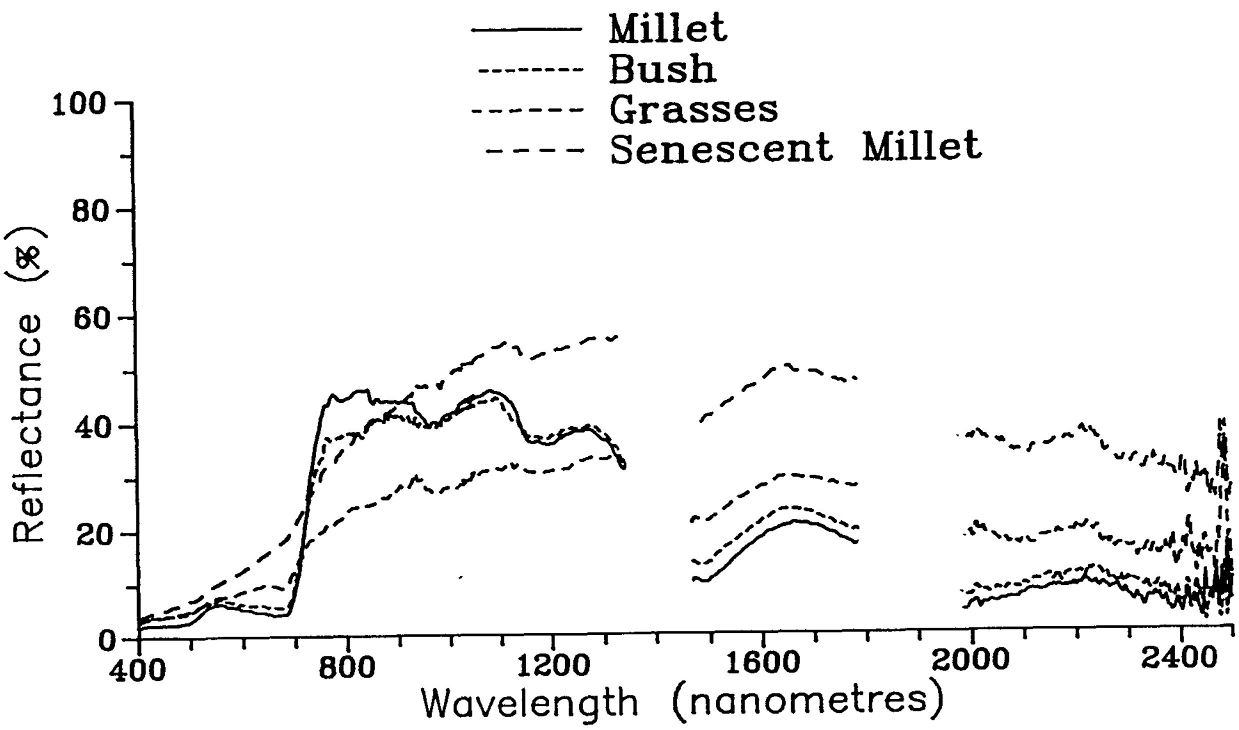

Figure 1 Reflection Spectra of Vegetataion

be seen from Figure 1 that millet can be expected to have a greater transpiration capacity than the bush, which is greater than the grasses.

The general increase in absorption at wavelengths greater than 1000 nanometres is ascribed by Gausmann et al (1978) to the presence of water in the leaves. This feature can be used as a measure of the amount of leaf water. In Figure 1 the amount of leaf water of millet is greater than that of the bush which is greater than that of the grasses.

In semi-arid environments these features of the reflection spectra of vegetation can be used to provide information about the amount and distribution of subsurface water that is near enough to the surface to be utilised by vegetation. The effect of rain fed vegetation can be reduced by selecting remotely sensed data that was imaged during the dry season so that all active vegetation is due to the presence of 'permanent' subsurface water. The vegetation index, calculated from the remotely sensed data, will then be a measure of the transpiration of the vegetation. The controlling factor, other than man's activities, on the transpiration is likely to be the amount of water available to the vegetation. Thus, the higher the vegetation index the more subsurface water may be present.

Similarly, the information from the ratio between the reflectance in the portion of the spectrum from 1500 to 2500 nanometres, and that in the near infra-red, 760 to 900 nanometres, can be used as a water content index which will give information about the amount of leaf water. However, variations in surface soil water will have similar effects and there are some minerals that have strong absorption bands in this part of their spectrum so care is need in interpreting this index.

Another source of information is the thermal band, 10000 to 12000 nanometres. Variations in the temperature of vegetation are a function of transpiration but soils and soil moisture also produce variations. In general, the lower the temperature observed over vegetation then the more transpiration. In terms of data from the Landsat satellites there is a disadvantage in that the spatial resolution of the thermal data, 120m, is four times coarser than that of the optical bands, 30m. Nevertheless it can provide confirmation of the vegetation index.

Data

Two Landsat Thematic Mapper scenes were obtained for the study. The path/row numbers of these scenes were 169/074 and 160/075 and cover swaths 185 km wide of SE Zimbabwe. Both scenes were imaged on 23rd July 1986 at approximately 7:27 GMT.

Location of test areas

The large areas covered by the images precluded a detail analysis in the short time of this study. Therefore three smaller, rectangular areas were selected for analysis. These areas were selected for three main reasons:

- They represented the major geological units.
- They were covered by an existing BGS borehole survey.
- They were areas where rural water supplies were required.

The relevant geological units are:

Area 1 - Beitbridge system, early Cambrian paragneiss and other high grade sediments.
Area 2 - Gneisses of the Limpopo Mobile Belt
Area 3 - A Younger Intrusive Granite

The locations of the areas are:

	Bottom left corner	Top right corner	Area(km^2)
Area 1	270000 7670000	298000 7700000	924
Area 2	290000 7705000	310000 7738000	660
Area 3	314000 7734000	328000 7747000	182

Initial processing of the remotely sensed data

The remotely sensed images of all three areas were geometrically registered to the UTM grid so as to allow direct comparison with map data. Control points, usually river or stream confluences, on the images and the 1:50000 scale maps of the areas were identified and used to geometrically correct the remotely sensed data by using nearest neighbour interpolation, resampling to the same pixel size as the original data so as to reduce errors.

The correlation matrix of the Thematic Mapper (TM) optical bands, Table I, shows that there is strong correlation between all the bands, i.e. there is considerable repetition of information. However, it can be seen that band 7 has the least

Band	*1*	*2*	*3*	*4*	*5*	*7*
1	*1.000*	*0.977*	*0.925*	*0.948*	*0.911*	*0.851*
2	*0.977*	*1.000*	*0.972*	*0.952*	*0.954*	*0.916*
3	*0.925*	*0.972*	*1.000*	*0.915*	*0.974*	*0.962*
4	*0.948*	*0.952*	*0.915*	*1.000*	*0.923*	*0.847*
5	*0.911*	*0.954*	*0.974*	*0.923*	*1.000*	*0.975*
7	*0.851*	*0.916*	*0.962*	*0;.847*	*0.975*	*1.000*

Table I Correlation matrix for TM bands

correlation with other bands and in particular with band 4, which is the band corresponding to 760 to 900 nanometres. The visible band with the least correlation to bands 4 and 7 is 3, red, and so all false colour composites were compiled using the combination of bands 4, 7 and 3.

The interpretation of remotely sensed data is best done with some ground information available. Without this it is often difficult to produce a unique interpretation. This analysis has been done with a very limited ground truth data set. General geological maps and the 1:50000 topographic maps provide some useful information. The BGS well inventory of the areas is also very helpful. However, additional information is required for definitive answers to be provided.

The limited time of this study has not allowed any further work to be done on Area 1

Area 3

This area is set in the Ndanga communal lands with the river Chenyu running approximately WSW through the area. Figure 2 is a decorrelation stretched false colour composite of bands 4, 7 and 3. The actively growing vegetation shows as red areas and can be seen to be concentrated along the lines of rivers and in the hilly areas. The vegetation on the hills is probably present mainly due to reduced human activities, that along the rivers is probably due to subsurface water associated with channel deposits.

The vegetation index image, figure 3, also shows this distribution but picks up areas where vegetation is moderately active, shown by the mid-grey tones. It is these areas where there may be larger supplies of subsurface water. The areas occur on the northern flanks of the hills running WSW across the southern part of the area and there are areas in the north-east corner of the area, associated with the rivers. Particularly interesting is the large area in the centre left of the image. This area is almost certainly associated with greater subsurface water as the rivers traverse it and it does not seem to be associated with any other feature. These areas may be a result of human activity, either due to being subject to less grazing pressure, or not exploited by crops but without further ground information this cannot be verified.

The areas are confirmed by the thermal image, figure 4, to be due to vegetation. The areas with high vegetation indices appear as lower brightness temperatures. This can be explained as greater soil moisture but, as the imagery is from the dry season, this seems unlikely. The most likely explanation is that there is more vegetation transpiring in these areas.

The water content index, figure 5, shows a similar variation to the vegetation index although it is less obvious. The white areas are due to vegetation associated with the river beds and the hills. However the same areas that appeared as mid-grey tones on the vegetation index image are also apparent as mid-grey tones in this image. These areas could be due to greater soil moisture in the soil profile close to the surface, but this seems unlikely as the data was acquired during the dry season. It could also be due to changes in the soil or rock types but the coincidence with the features in the thermal band and the vegetation index suggests that an interpretation in terms of vegetation water is correct.

The remotely sensed data shows that there are distinct areas where there is vegetation with a greater amount of leaf water and more transpiration. Some of these areas have little relationship to the river system and their position in relation to the settlement pattern of the area suggest that they are probably not due to human activity. Therefore the most likely explanation is that there is greater availability of subsurface water. This may be due to the water table being nearer to the surface or due to greater storage capacity for water in the soils and rocks of these areas. Unfortunately, none of the wells occur in these areas and so there is no direct evidence that these conclusions are correct.

The remotely sensed data also shows clear indications of linear features and, as these may be a source of subsurface water, an analysis of their distribution has been carried out. The positions of the linear features were manually interpreted based on several differently processed images. A decorrelation stretched false colour composite of bands 4, 7 and 3, and principle component 1 of all bands were the most useful images. The position of the lineations and the specific capacities of wells, are shown in figure 6. Histograms of the lineation orientations and lengths are shown in figure 7. These are similar to those obtained by Greenbaum (1988) and so are almost certainly fractures. The histogram of orientations shows two modes, around 60^{o} and 150^{o} which are orthogonal and so probably represent the same set. There is another, smaller mode around 90^{o}. The histogram of the lineation lengths has a mode around 800m but there are lineations with lengths up to 3200m.

The drainage network of the area is basically a dendritic pattern, only partially controlled by the position of the fractures. This suggests that the lineations do not represent structures that are significantly different to the surrounding rocks in terms of their resistance to erosion and thus may not be significant in terms of subsurface water.

The locations and specific capacities of the wells and the location of lineations were input to a Geographic Information System (GIS) in order to test whether there was any link between high specific capacity and proximity to a lineation. Values for specific capacity are available for 16 wells. The histogram of the specific capacities, Figure 7(c) shows that 3 wells have exceptionally high specific capacities, i.e. greater than 0.1 litre/s/metre drawdown. There is uncertainty in the exact position of both the wells and lineations so it was decided to assume an error zone of 100m around the locations of both. Thus, wells greater than 200m from a lineation were considered to be definitely not associated with the lineations. Wells within 200m of a lineation might be associated with it. Five of the wells are within 200m of a lineation and 2 of these have a specific capacity greater than 0.1 litre/s/metre drawdown. The lineations associated with these wells are roughly of east-west orientation. These lineations are associated with vegetation and show up on both the vegetation index and water content index images. Although the number of wells is too few to allow a statistical test of significance, the association with vegetation does suggest that east-west lineations might be associated with higher yielding wells.

Area 2

This area lies to the west of Lake Bangala. Figure 8 is a decorrelation stretched false colour composite of bands 4, 7 and 3. Part of Lake Bangala can be seen as the blue area in the south-east quadrant of the image. The fence line between the communal lands and the Tokwa River Ranch appears as a diagonal line in the south-west quadrant. The pattern of vegetation is similar to that in Area 3. The vegetation index image, Figure 9, shows that the greatest amount of vegetation is concentrated along the lines of rivers and in the hilly areas, as in Area 3. The Mutetenu valley, in the centre of the area, shows low values whist, in the northern part of the area there are patches of low values. This suggests that the pattern may be due to human activities, rather than subsurface water. However, there is a large area in the north-west where the vegetation index is relatively high.

The water content index, figure 10, shows similar features to the vegetation index. The valley bottoms shows as areas with reasonably high leaf water content. The north-west quadrant does have areas of higher amount of leaf water in the low lying areas. These areas show about the same levels as found within the Tokwa River Ranch area so it is uncertain whether this is generally an area where subsurface water is more abundant or there is less pressure from human activities on the vegetation.

The analysis of the linear features shows a generally similar trend to that in Area 3. The histogram of orientations, Figure 11(a), shows two modes, around 50^{o} and 140^{o} which are orthogonal and so probably represent the same set of fractures. There is a small mode at 90^{o}. The histogram of lineation lengths shows a mode at around 400m, half the length in Area 3, but there are lineations with lengths up to 3200m. Four wells are within 200m of a lineation, Figure 12. All have low specific capacities and are close to a north-east or north-west trending lineations. The histogram of well specific capacities shows that no wells have specific capacities greater than 0.1 litre/s/metre drawdown, reinforcing the hypothesis that east-west lineations may be areas of increased yield.

Conclusions

Additional ground truth is required to be certain whether the vegetation features are due to human activities or subsurface water. There are areas where it can fairly confidently stated that there is a greater occurrence of subsurface water, notably the central western part of Area 3. There is also strong circumstantial evidence that east-west lineations may be areas where higher yields from wells can be expected. Once these have been recognised on remotely sensed images, they can be located on the ground using geophysical methods such as VLF, EM or resistivity surveys.

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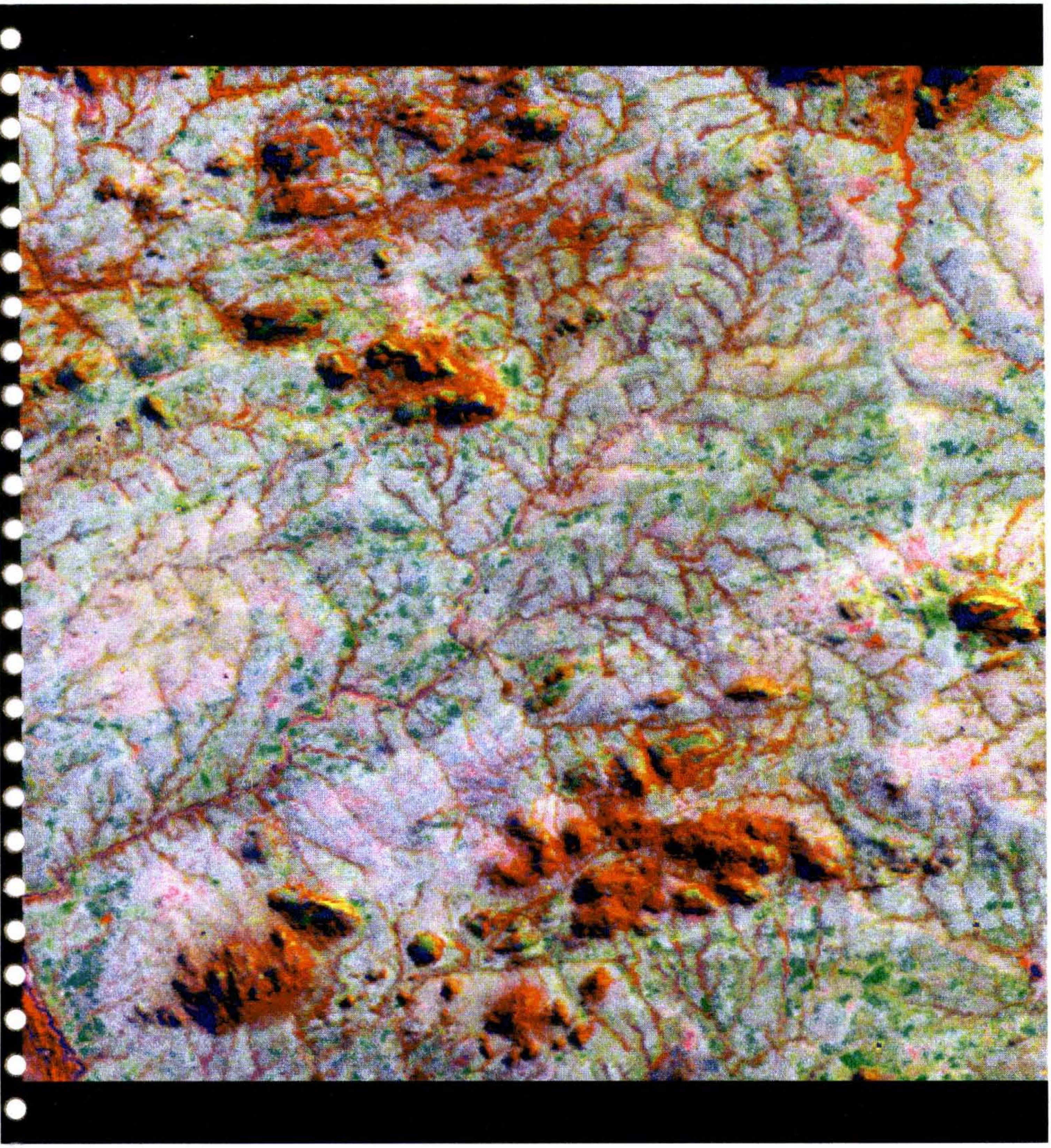


Figure 2 Area 3 - bands 4,7,3   approx. scale 1:72500

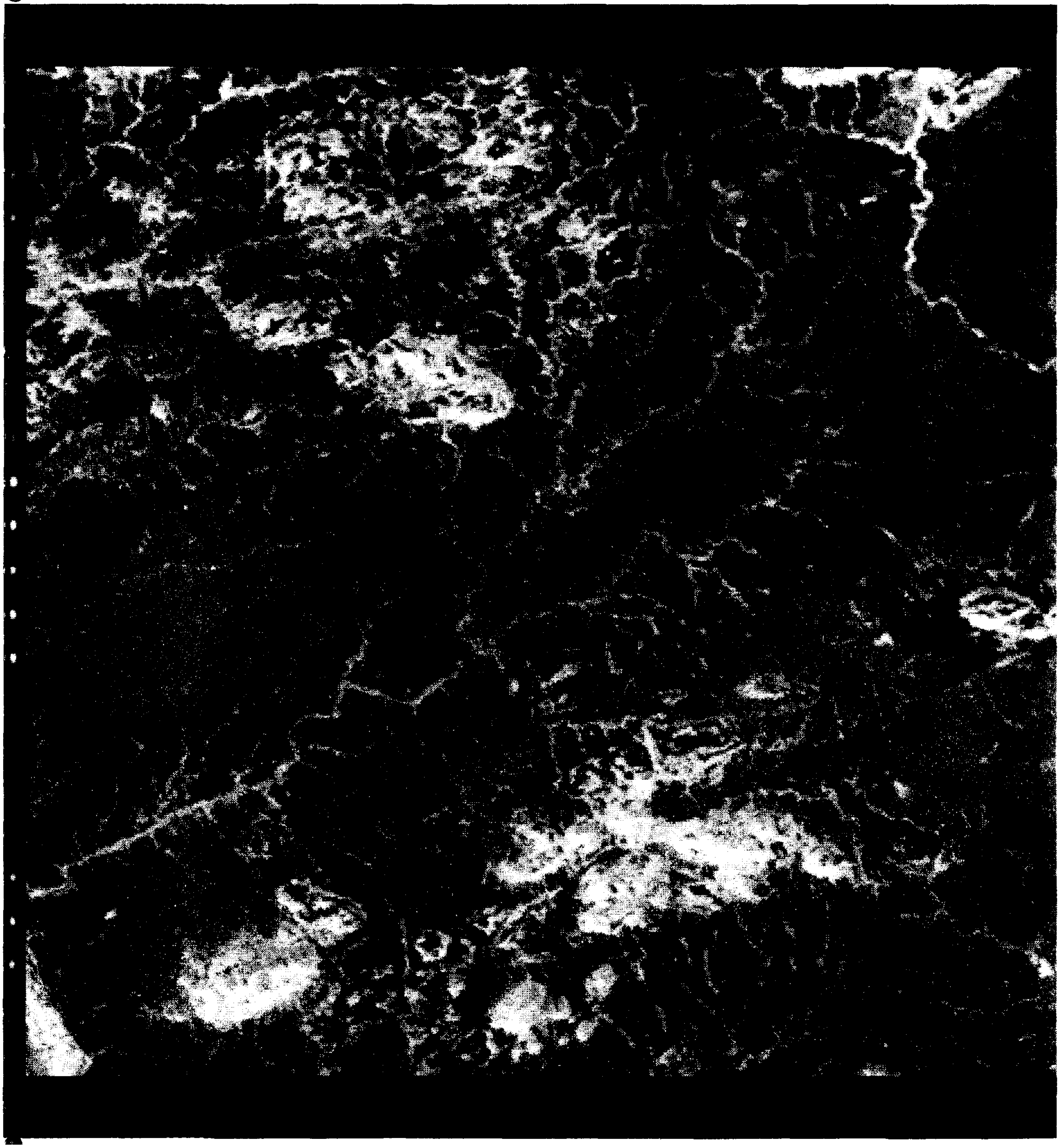


Figure 3 Area 3 - Vegetation Index approx. scale 1:72500

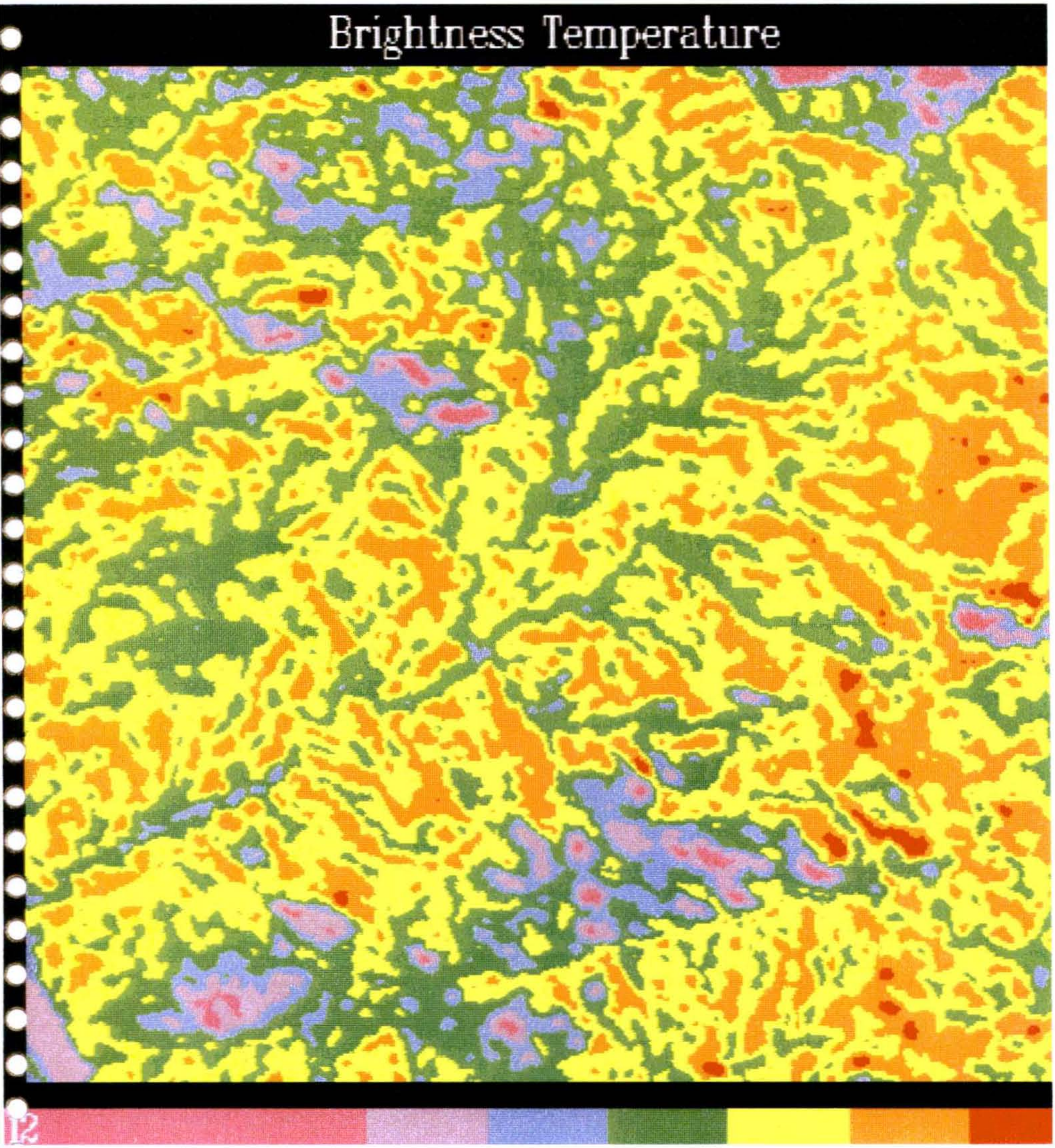


Figure 4 Area 3 - Thermal Image approx. scale 1:72500

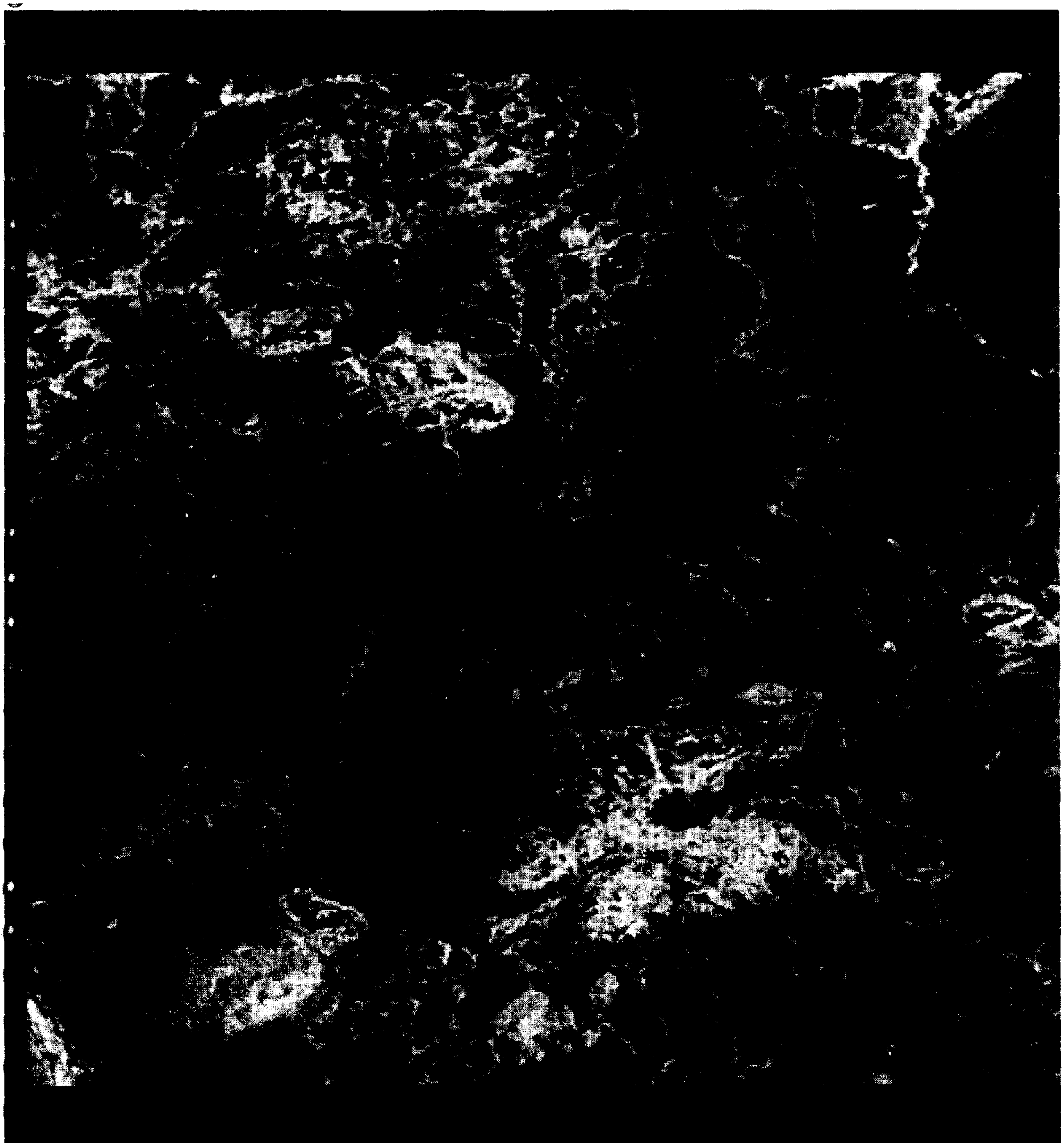
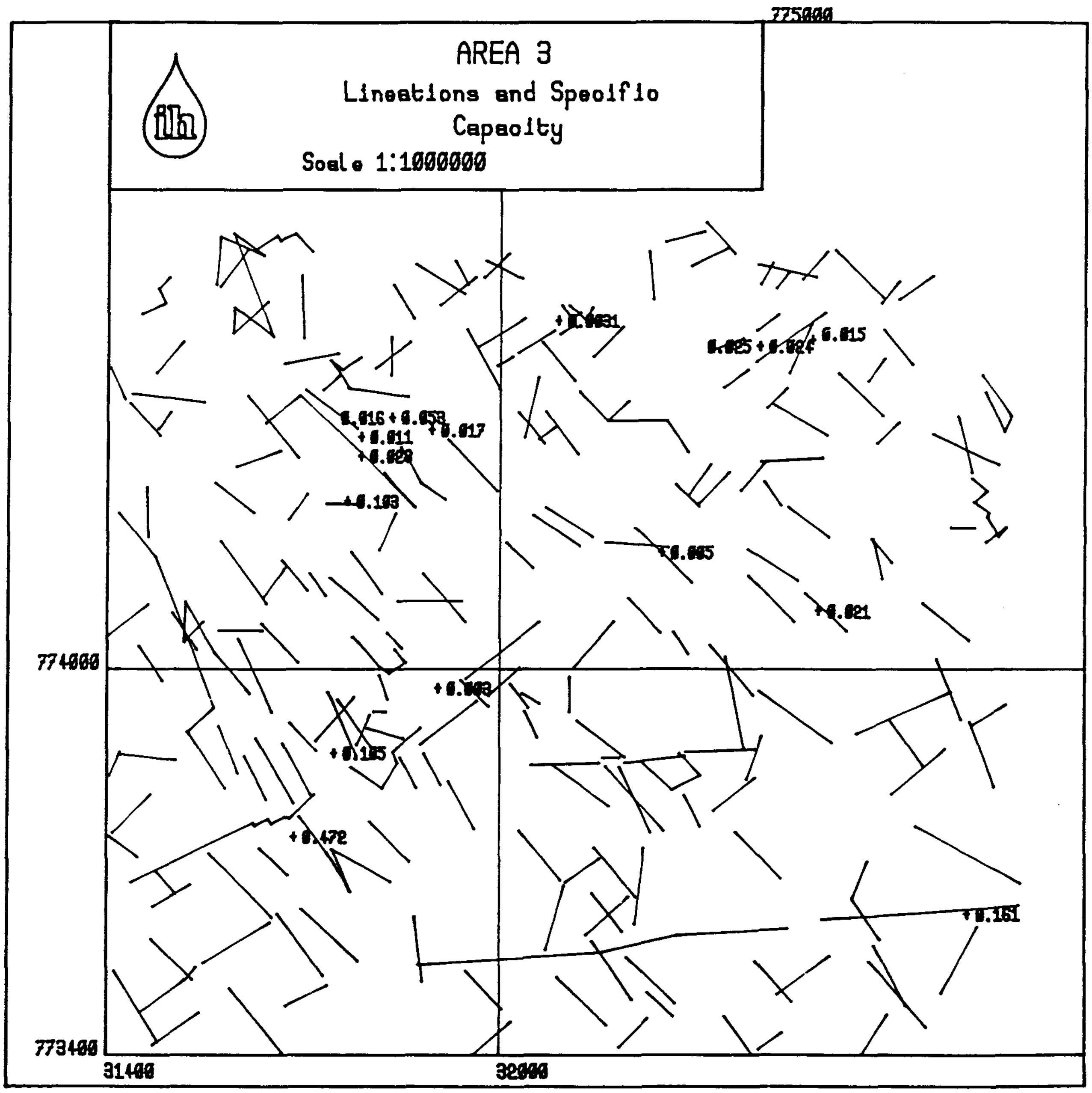


Figure 5 Area 3 - Water Content Index approx. scale 1:7250C

Figure 6 Area 3 – Map of Lineations and Wells



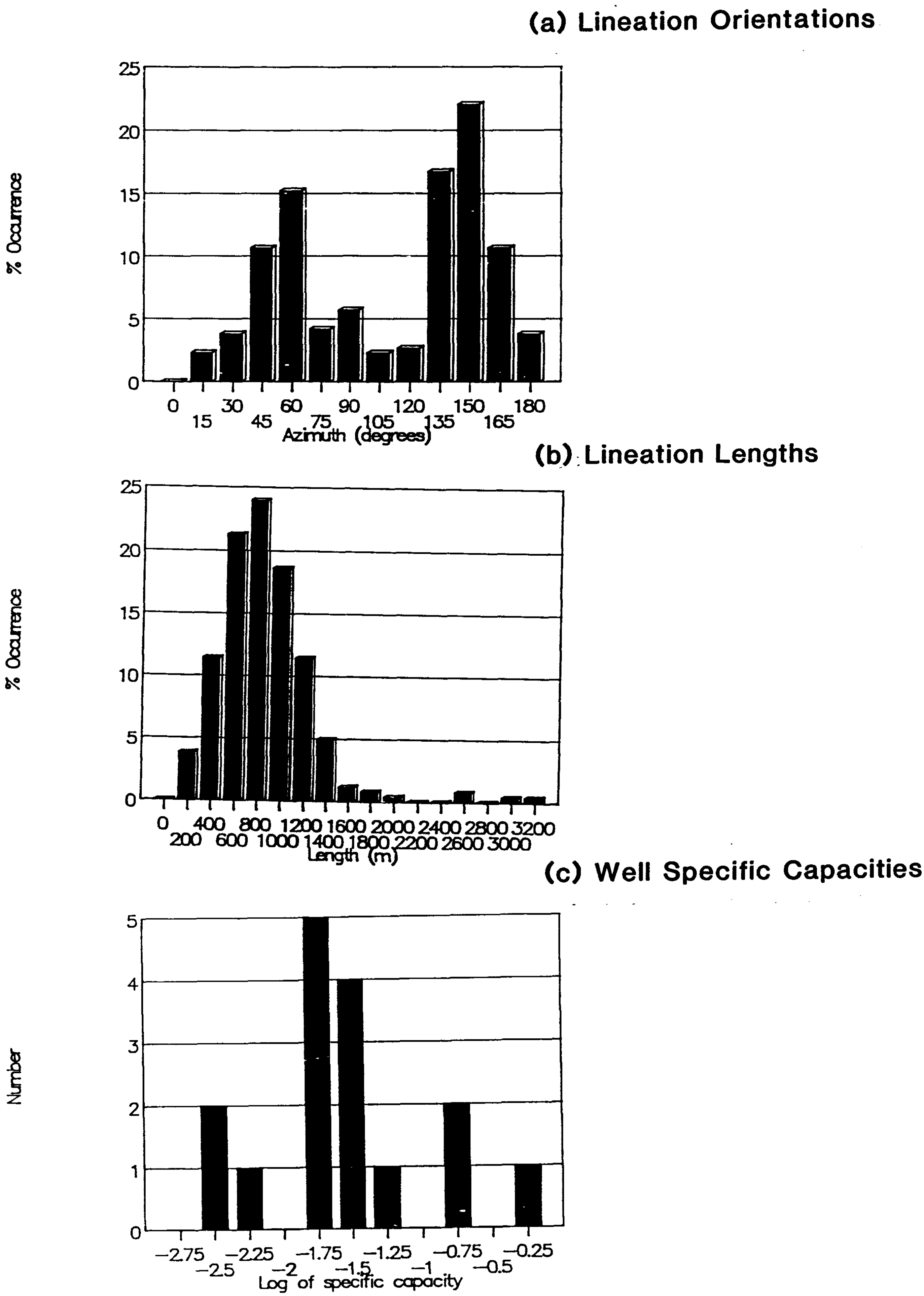


Figure 7 Area 3 – Histograms

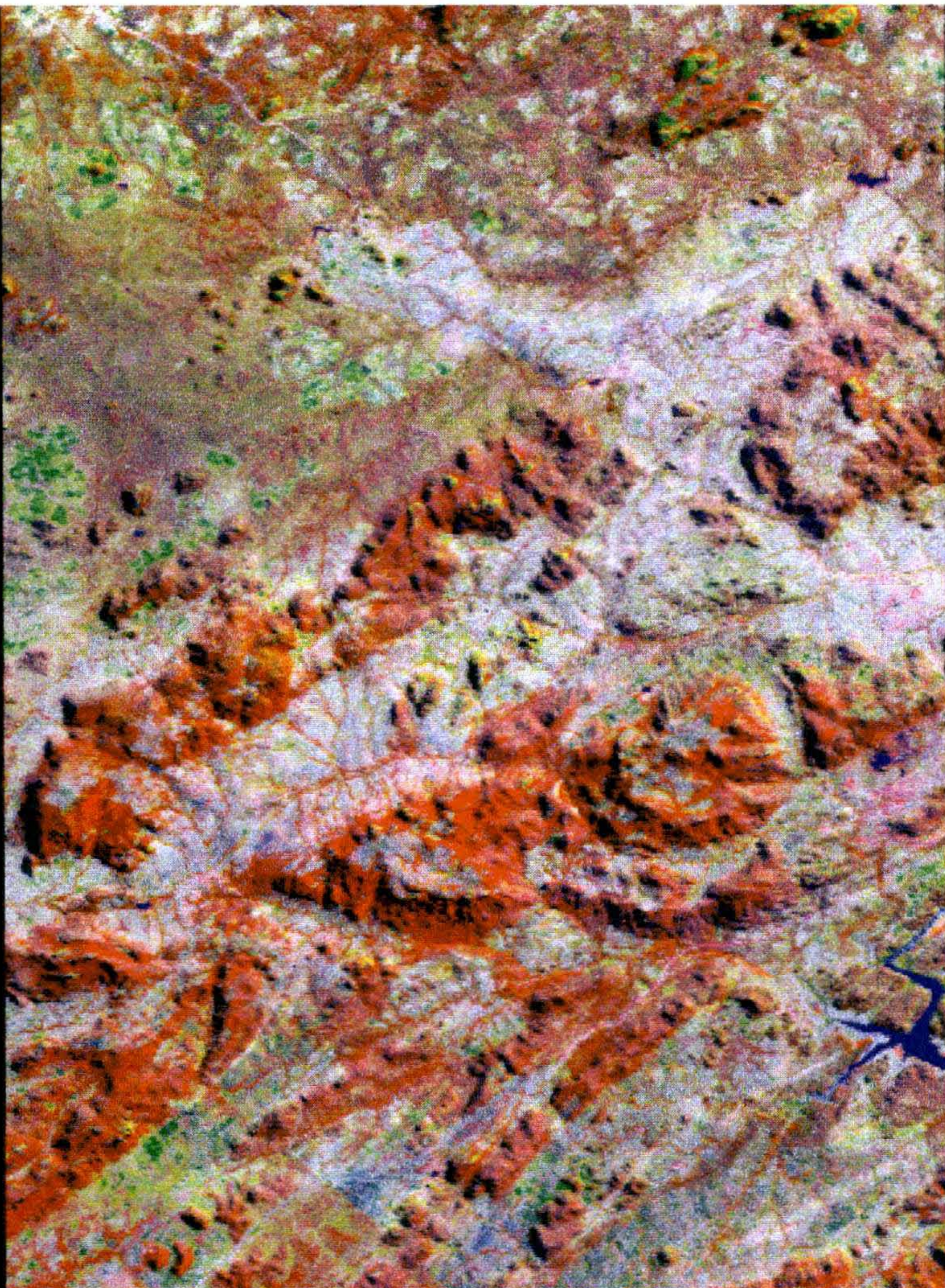


Figure 8 Area 2 - Bands 4,7,3 approx. scale 1:13400

Figure 9   Area 2 - Vegetation Index   approx.scale 1:13400

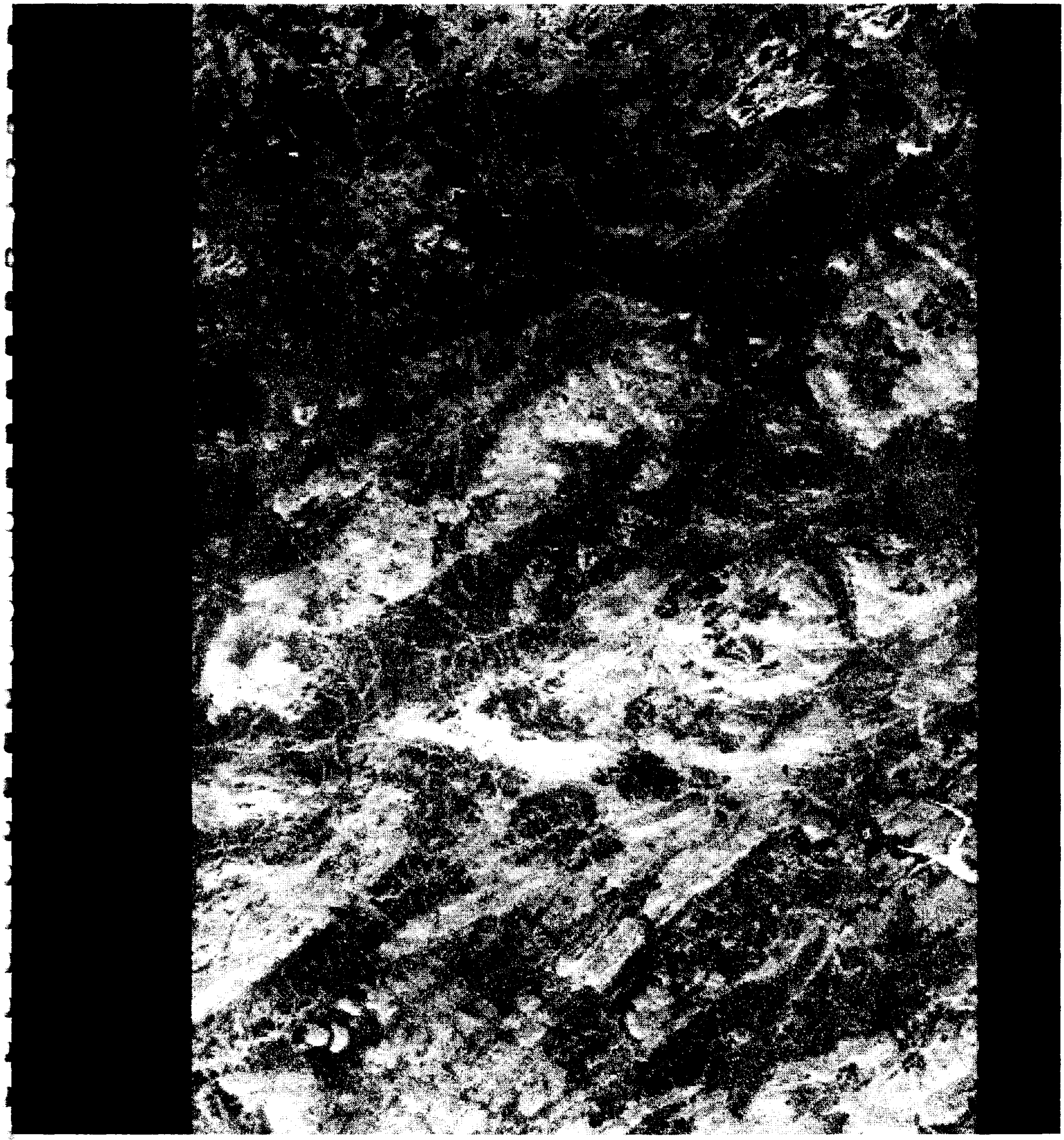


Figure 10   Area 2 - Water Content Index   approx. scale 1:1340(

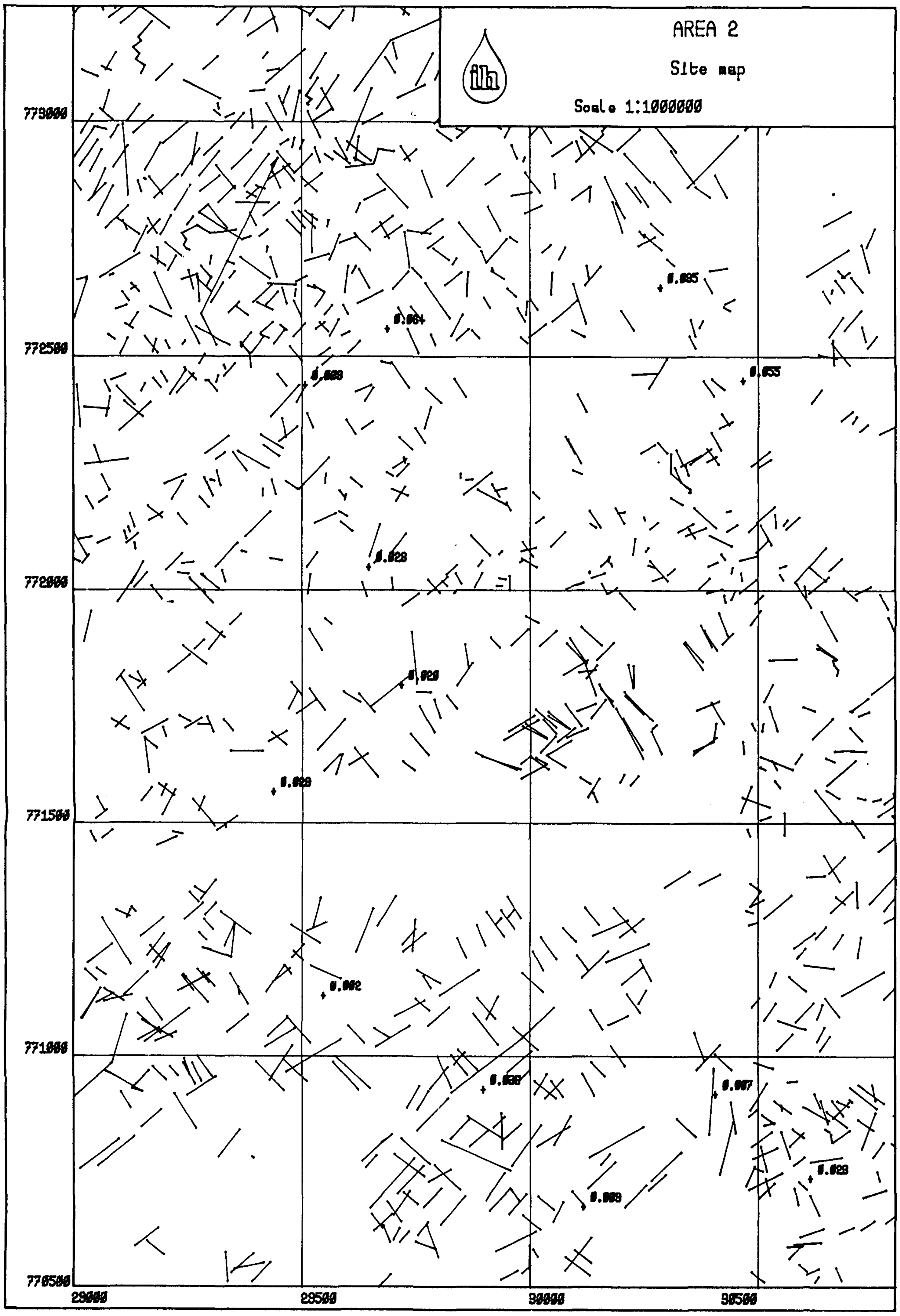


Figure 11 Area 2 - Map of Lineations and Wells

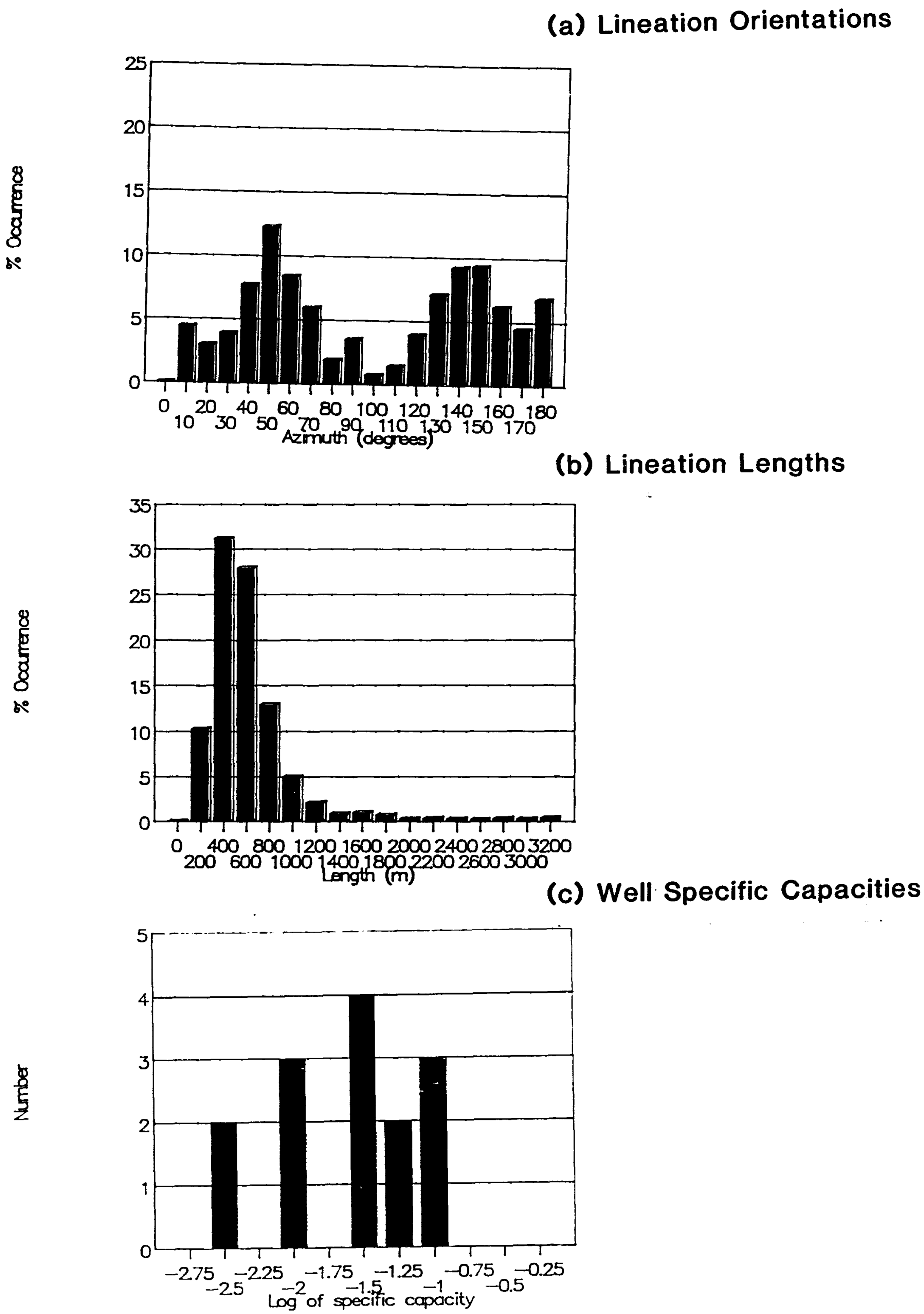


Figure 12 Area 2 – Histograms