Chapter 2 Airborne Geophysical Survey

2-1 Survey Area and Airborne survey specification

The objective of the survey is to clarify the geological structure and units and the expected alteration zones from combination of airborne magnetic and radiometric data, and Landsat images, and to interpret the metallogenic potential of the area.

The survey area is shown on Fig.II-1-1. The coordinates of the survey area are as follows:

14° 08' 35" N	122° 32' 10" E
14° 08' 35" N	122° 45' 00" E
14° 04' 00" N	122° 45' 00" E
14° 04' 00" N	122° 48' 50" E
14° 55' 00" N	122° 48' 50" E
14° 55' 00" N	122° 36' 00" E
14° 59' 00" N	122° 32' 10" E

Airborne survey specification is mentioned below.

Airborne survey was made by a helicopter considering the pronounced unevenness of the terrain as a part of peninsula with volcanos. The survey acquired high-resolution magnetic data, and also three gamma-ray spectral data.

(Airborne survey specification)

Flight line spacing: 200m
Flight line direction: North-South
Tie line spacing: 1000m
Tie line direction: East-west
Sensor height: 80 m
Magnetometer sample interval: ~5 m
Magnetometer cycle rate: 0.1second
Magnetometer resolution: 0.001 nT
Radiometric sample interval: 40~50 m
Radiometiric cycle rate: 1 second
GPS cycle rate: 1 second

The measurement and the interpretation have been undertaken by Fugro Airborne Survey (the former World Geoscience Corporation).

The equipment, acquired various datasets have been outlines in Phase-I report.

2-2 Geophysical Interpretation

Some main geophysical images are shown in this report, and outline of geological and alteration zone distributions are mentioned below. The detail survey data are refered in the report of Phase-II. The procedure of interpretation was reported by Btty and Harvey 1998a, 1998b,and 1998c (made by Fugro Airborne Surveys) on airborne survey in the Bicol Peninsula by MMAJ.

- Digital Terrain Model (DTM) (Fig. II-2-1).
- Total Magnetic Intensity Reducedto Pole(TMI-RTP) (Fig.II-2-2).
- Total count of gamma-ray spectral data, with a pseudocolour image (Fig.II-2-3)

- Potassium gamma-ray spectral image (Fig.II-2-4).
- Uranium gamma-ray spectral image (Fig. II-2-5).
- Thorium gamma-ray spectral image (Fig. II-2-6).
- Combined potassium, uranium, thorium (Ternary) gamma-ray spectral image as a three color composite (Fig.II-2-7).

Based on the characteristics of airborne magnetic and radiometric data, igneous rocks were distinguished and compared to the stratigraphy in the area.

Aside from the data of airborne magnetics, Landsat images (Fig.II-1-1) also utilized for the purpose. For the interpretation, primary classification was made based on the clear magnetic characteristics of TMI-RTP image and IVD image. The units were difined by means of TMI and Analytic Signal of Total Magnetic Intensity.

The magnetic data as TMI-RTP are characterized by high frequency responses due to shallow magnetic volcanic units. The majority is due to induced or normally magnetized bodies producing highs in the TMI-RTP, and dipolar anomalies with a dominant low in the TMI data. However, several negative anomalies in TMI-RTP indicate the remnant or reversely magnetized bodies (Fig.II-2-2). The geomagnetic units are often composite, however, data are not sufficiently detailed to map out the thin individual volcanic units. Many are portrayed as trend lines, these are shown where the trends are continuous for more than 600-700 m, i.e. across several flight lines.

The Landsat and DTM data clearly outline the dissected form of the now extinct strato-volcano of Mt. Labo. No other obvious volcanic centers are apparent in the topographic data, although the broad plateau west of Mt. Labo may represent the eroded roots of an older system. Magnetic modelling suggests former centers within Susungdalaga Volcanics including one just north of Susungdalaga Mountain.

The dominant contribution of surface or near-surface magnetic sources is supported by the magnetic modelling. However, over Mt. Labo, the Landsat data outline the presence of a surface blanket of dissected pyroclastic flows (Fig.II-1-1) which are non-magnetic and form a thin cover over the underlying magnetic units including andesitic lava.

The radiometric data, especially potassium, has been used where appropriates to further discriminate the geomagnetic units as well as to outline zones of alteration. The potassium gamma-ray spectral response is due to a number of factors, including lithology, potassic alteration and the degree of exposure. Alluvial materials can produce a high response due to a combination of the response of source material and high exposure. For example, Labo River has a characteristic high- K-anomaly due to these factors (Fig.II-2-4).

The magnetic data may also outline the alteration areas. These may be zones of low magnetic response due to magnetite destruction during hydrothermal alteration, as distinct from lows due to reversely polarized bodies referred to above. (Fig.II-2-2, Fig.II-2-3)

The thorium and uranium gamma-ray spectral data show similar patterns and reflect a broad lithological control. Pleistocene volcanics of Mt. Labo show low uranium –thorium response along the sediment-dominated sequences of Bosigon Formation in the northeast, and Tigbinan and Santa Elena Formations in the west. In contrast, Pliocene, Macogon and Susungdalaga Volcanics through the center of the area show a higher response (Figs.II-2-5, II-2-6).

The ternary radiometric image (Fig.II-2-7) is broadly divisible into areas with lower uranium and thorium, and higher potassium with pink hues in the east and west, and a broad zone with higher uranium and thorium with cyan hues in the center. The central area is associated with

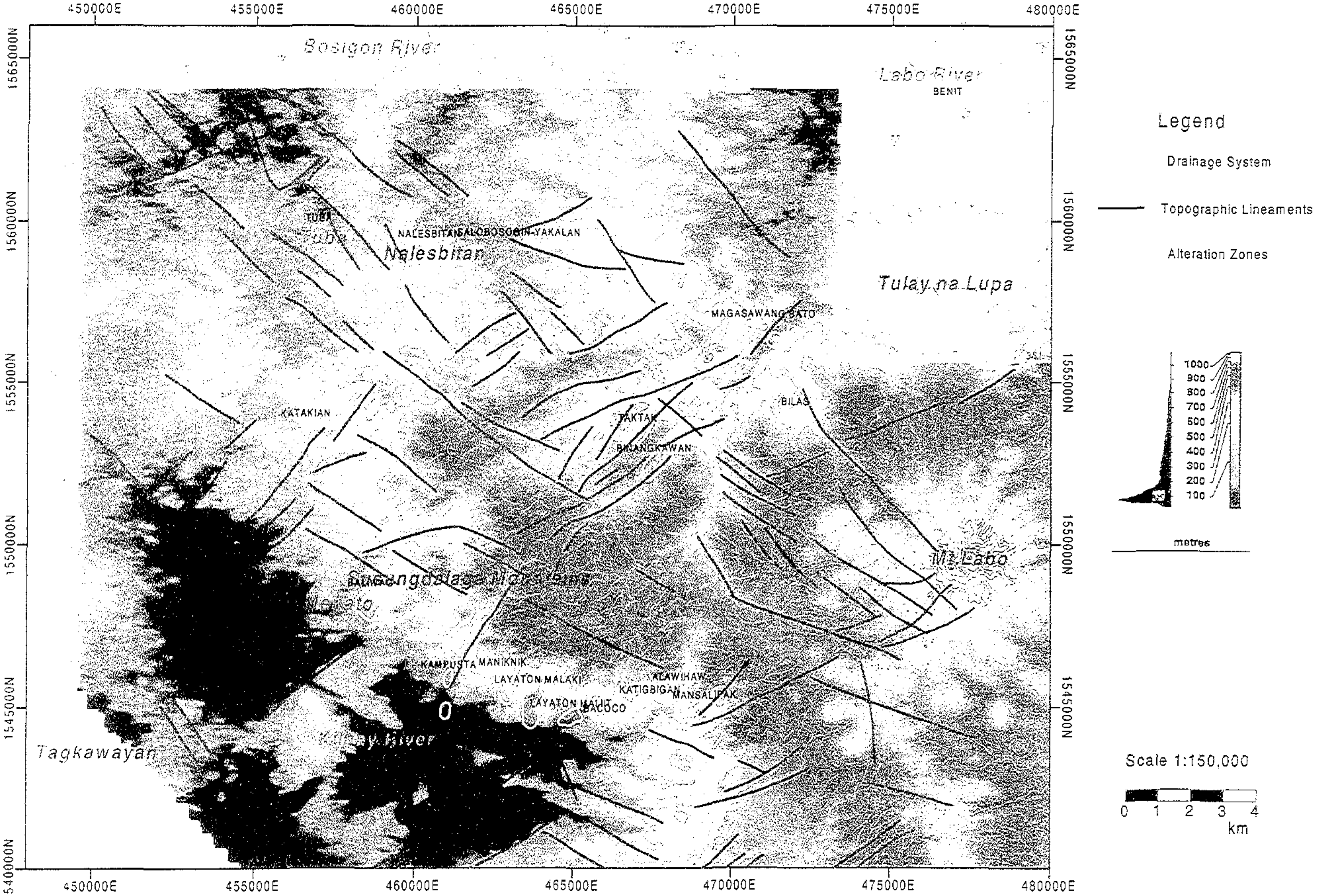


Fig. II-2-1 Digital Terrain Model Image

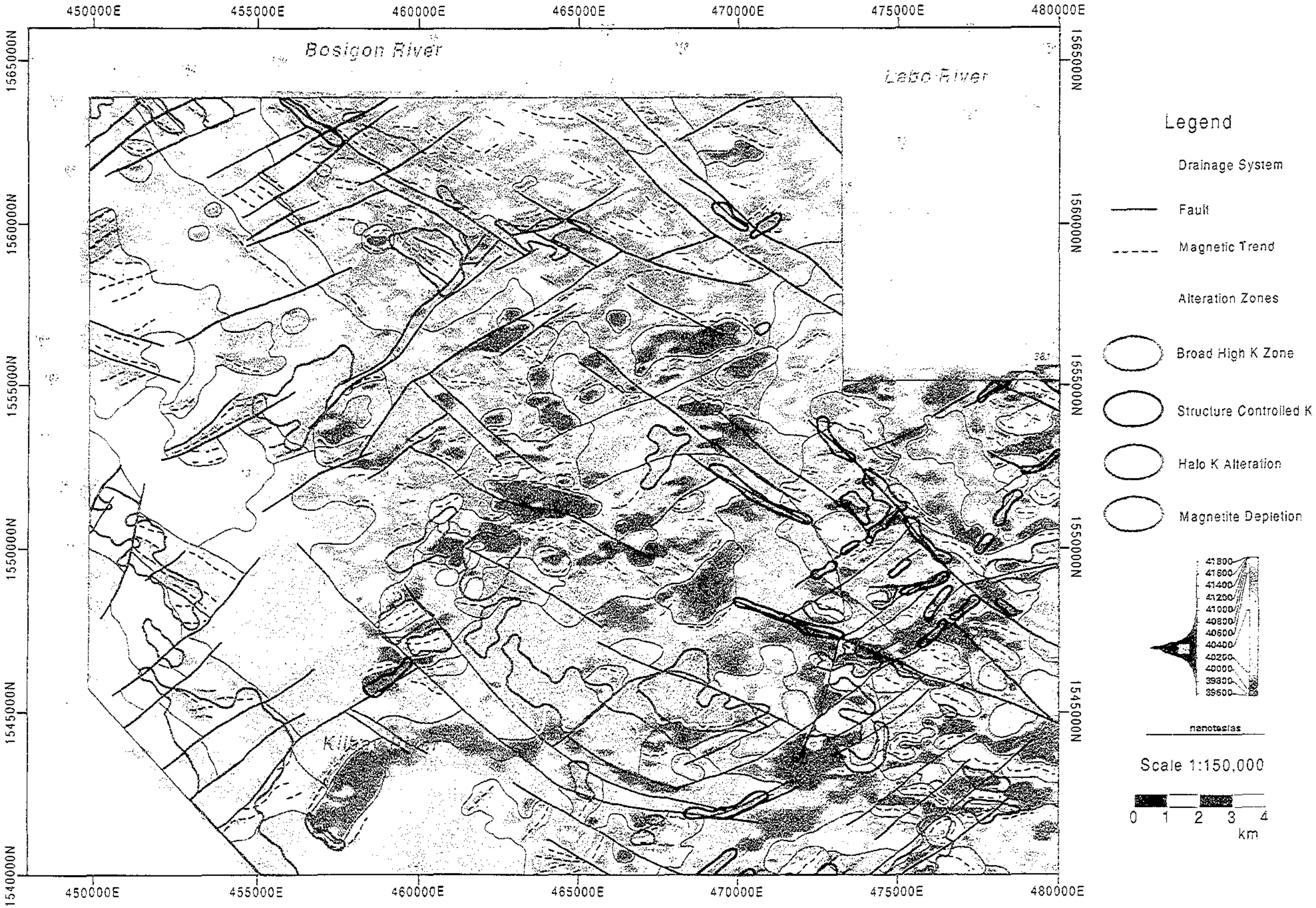


Fig. II-2-2 Total Magnetic Intensity Reduced to Pole Image (TMI-RTP)

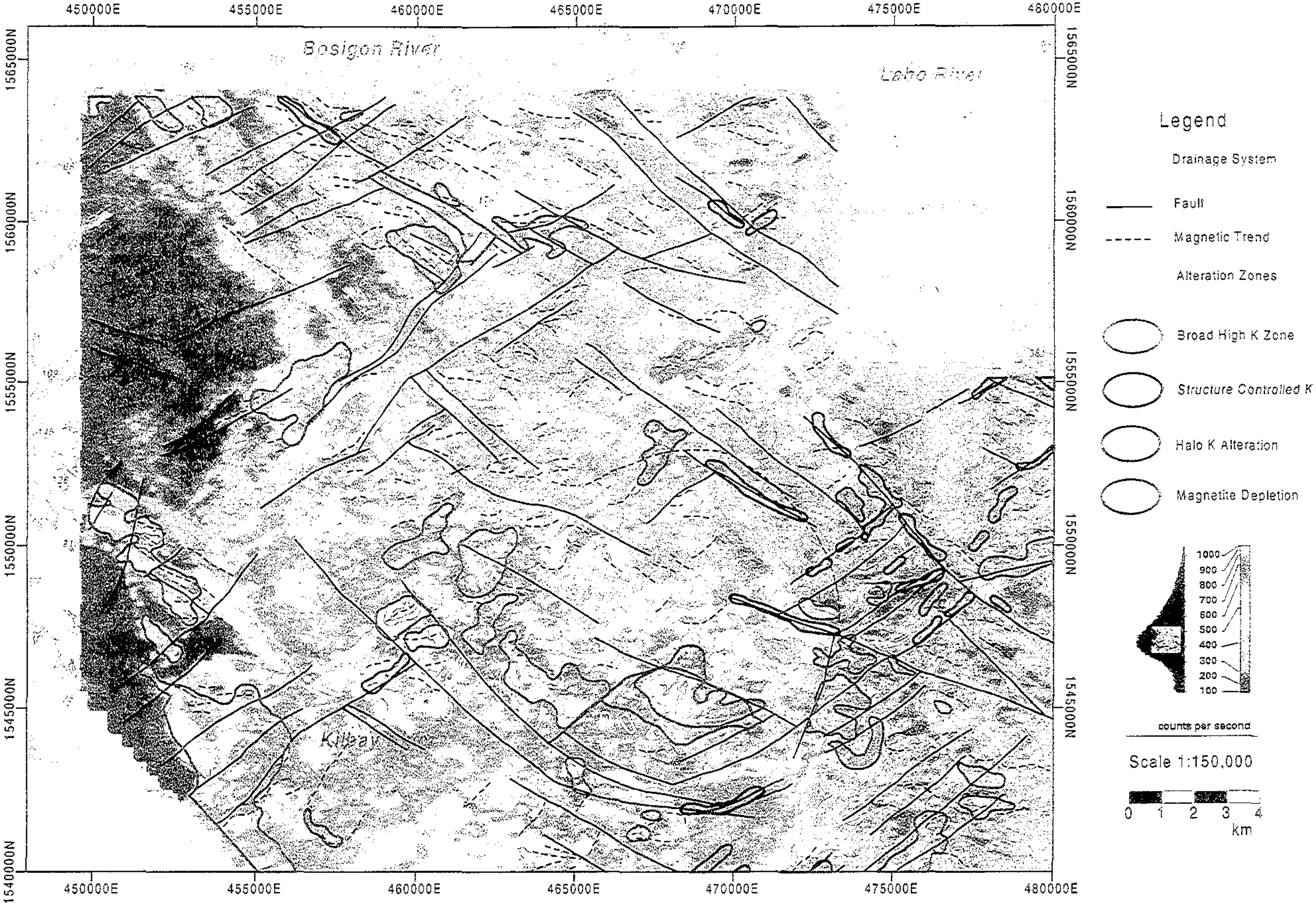


Fig. II-2-3 Total Count Gamma-ray spectral Image

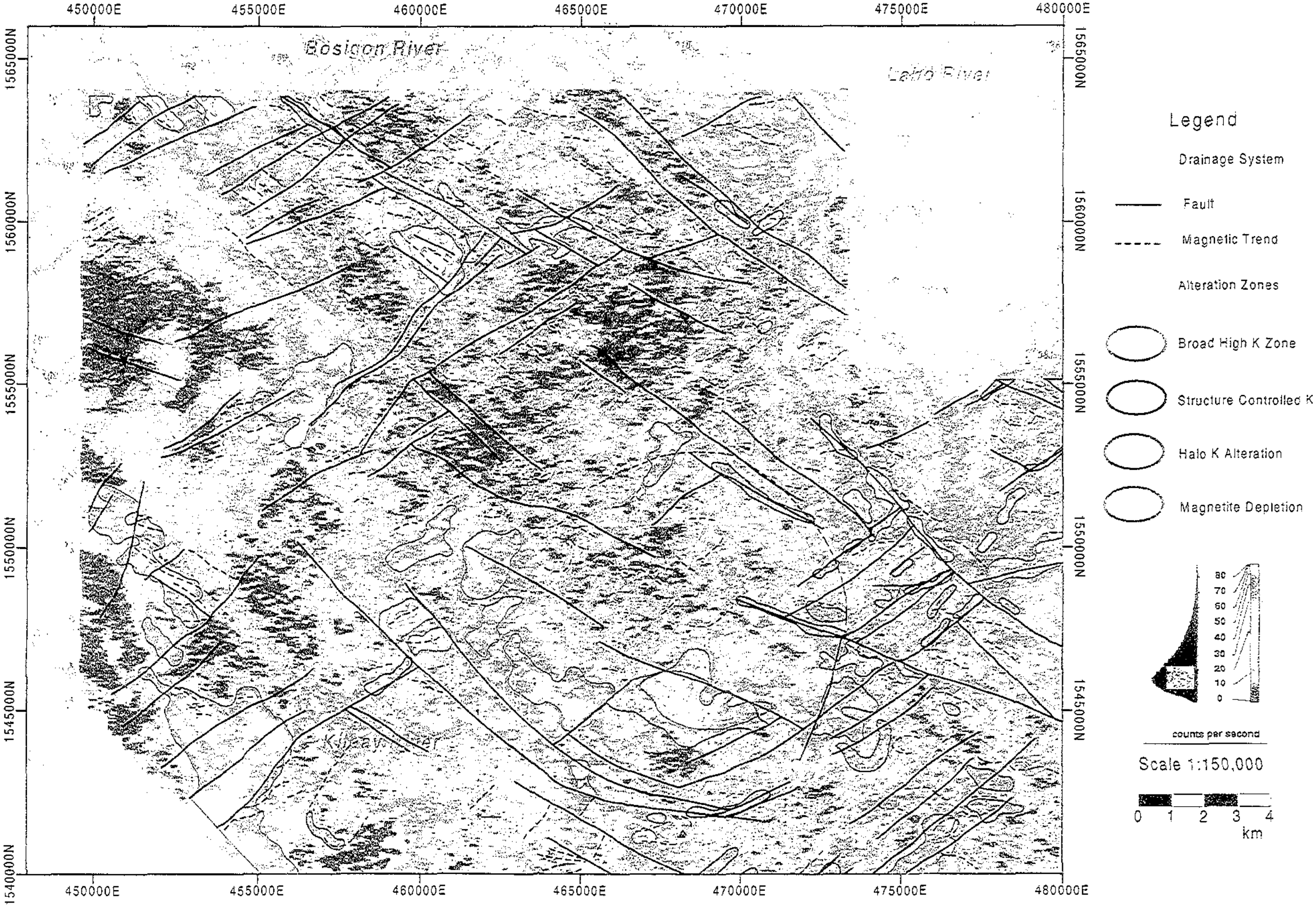


Fig. II-2-4 Potassium Gamma-ray Spectral Image

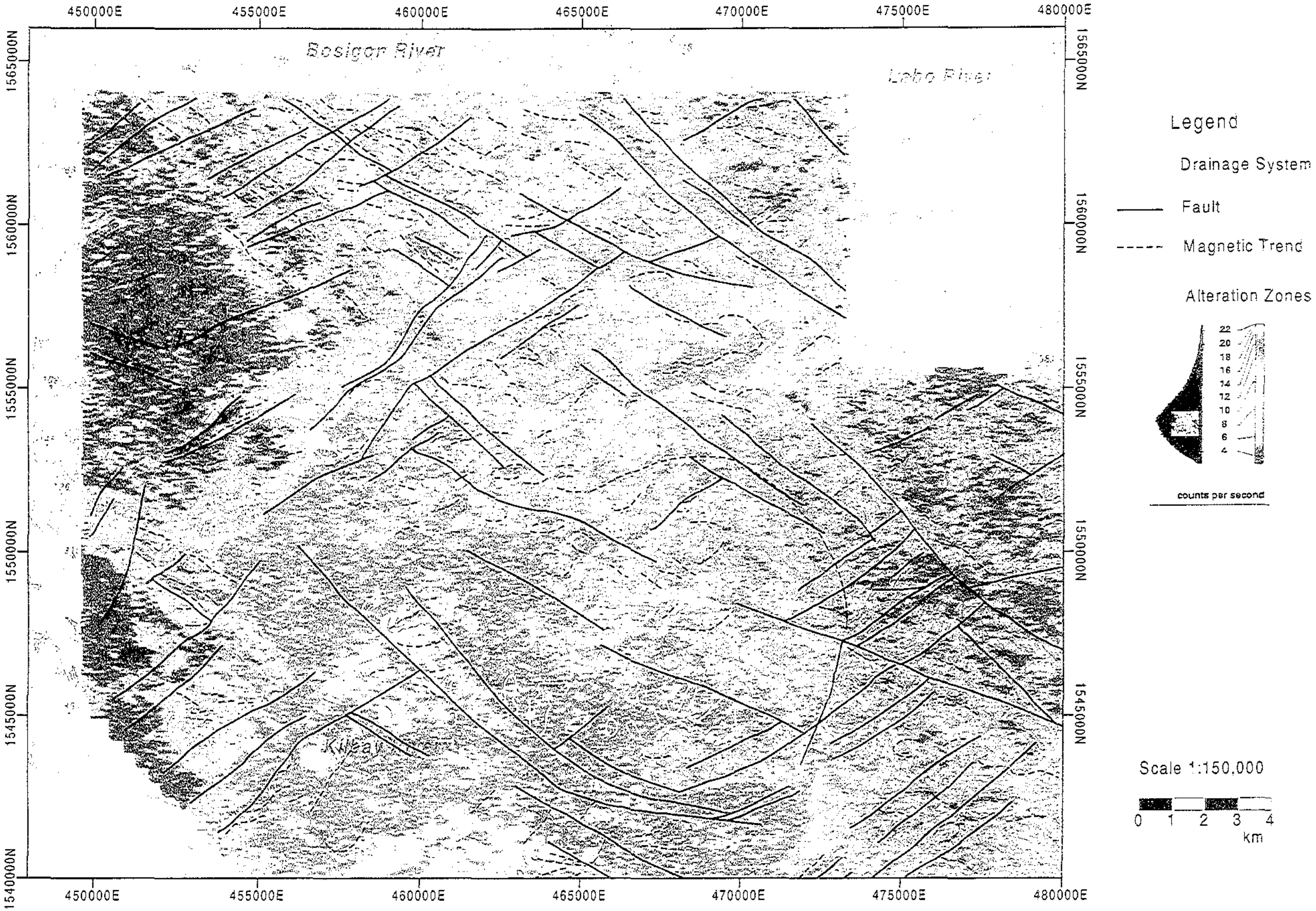


Fig. II-2-5 Uranium Gamma-ray Spectral Image

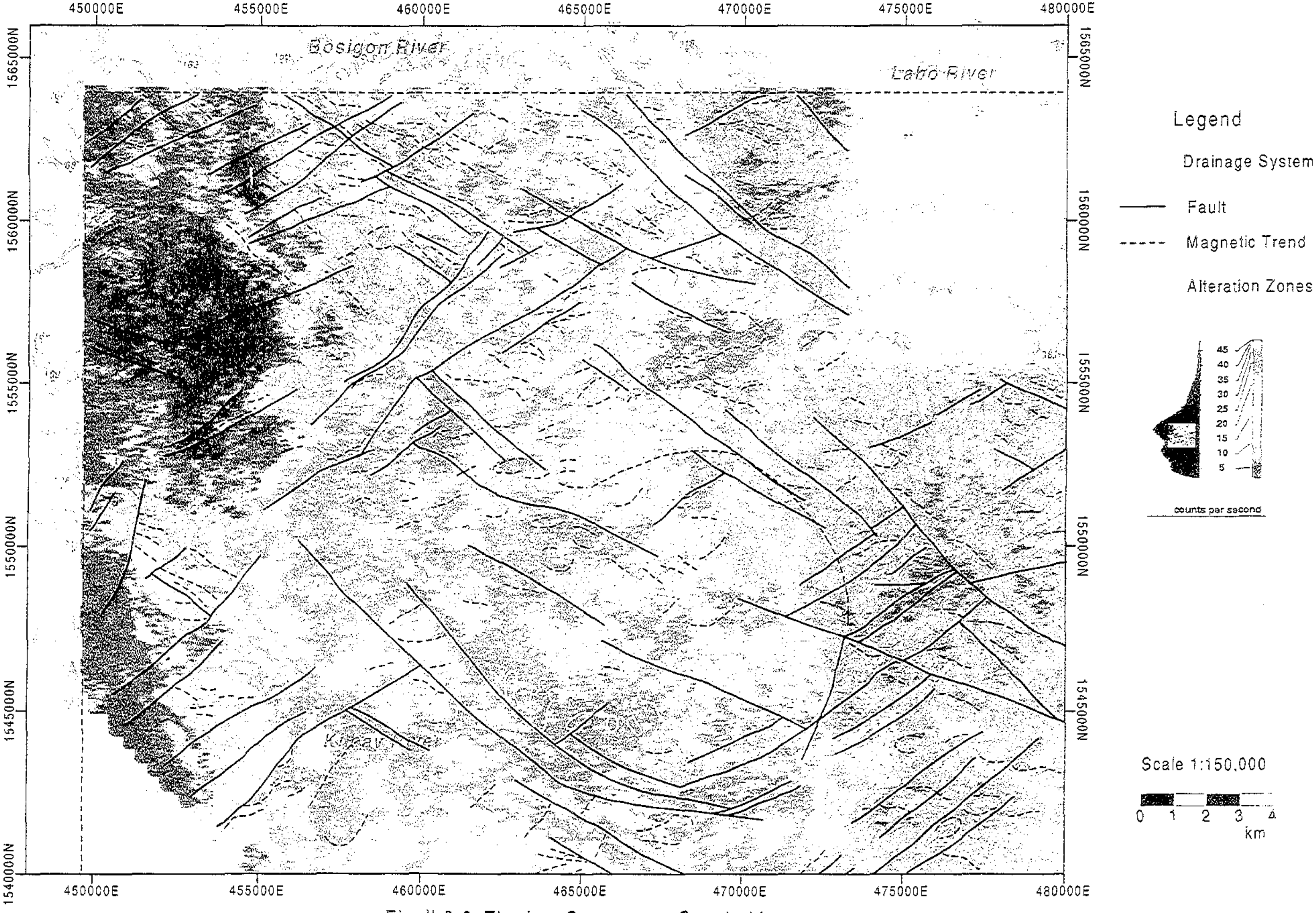


Fig. II-2-6 Thorium Gamma-ray Spectral Image

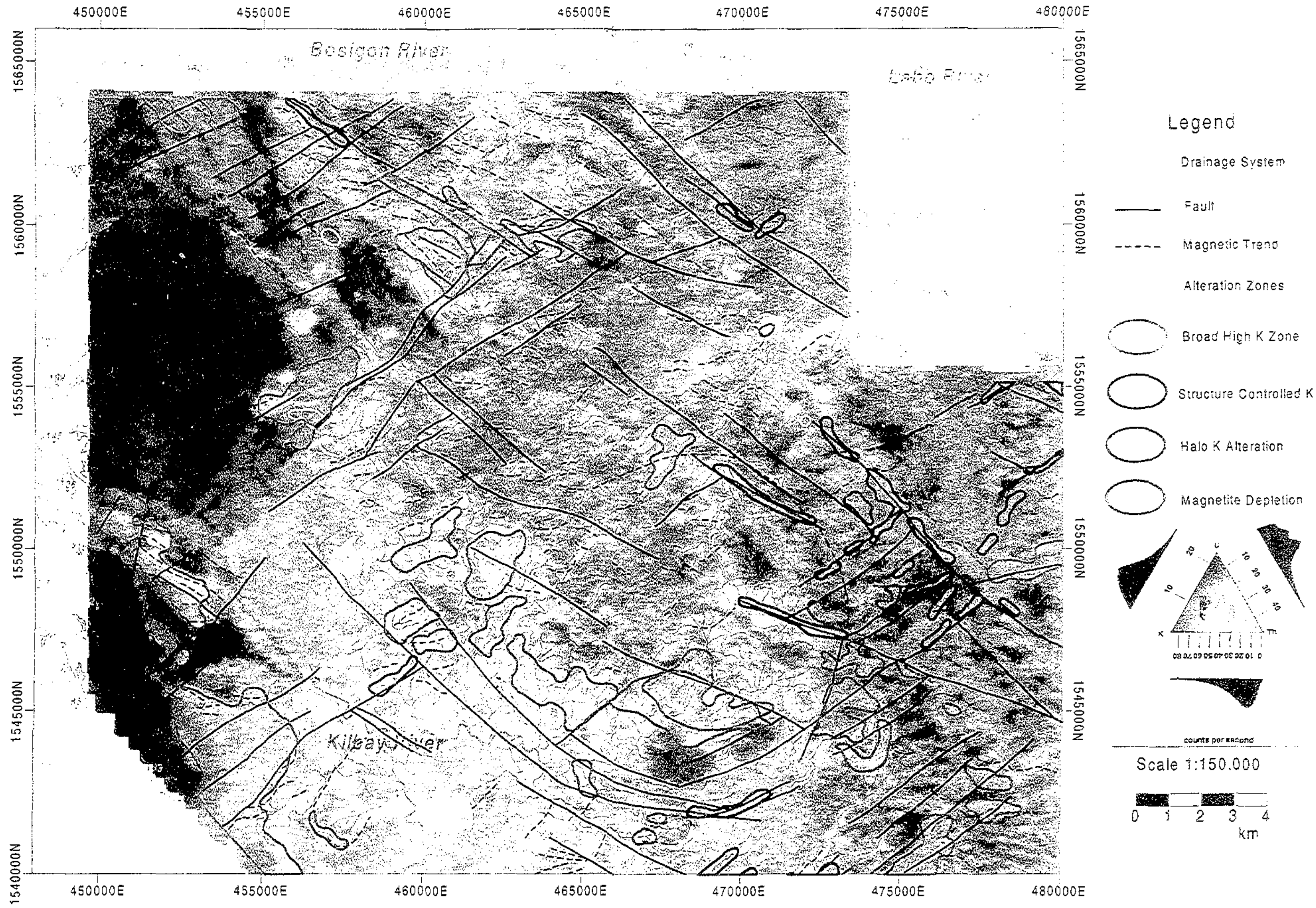


Fig. II-2-7 Ternary Gammma-ray Spectral Image

Pliocene Volcanics, local white to pink hues within it represent areas of alteration and/or high potassic lithologies.

The comparison between phisical characteristics and rock facies was made as above. The conclusion is shown in Table II-2-1 and Fig.II-2-8.

Table II-2-1 Units defined in the geophysical interpretation

Map Unit Code	Description
Undifferentiated Cenozoic Intrusives	
CzIm	Small plugs often with remanent magnetization, intruding Macogon Formation and older sedimentary sequences
CzIr	Composite bodies with reversed remanent magnetization, occasionally positive outer margins or high potassic zones (CzIr-k)
CzIp	Small magnetic plugs and domes. Possibly some associated with former volcanic centers; some with high K suggests felsic character. Intruding Susungdalaga Volcanics
CzIg	Early Cenozoic granodiorite/diorite with moderate K response and non -magnetic character
Pleistocene Labo Volcanics	
QLpf1 and Qlpf2	Andesitic to dacitic pyoclastic flows, non-magnetic, includes most recent units around summit and north side of Mt. Labo, and a tongue of older high Th flow unit to southwest. Shown as overlay unit to geomagnetic units described below.
QLcc	Moderately to highly magnetic lava flows, probably andesite
QLbum	Moderately magnetic volcanic unit including lava, older than QLcc
QLbun	Weakly to non-magnetic volcanic unit, including altered and weathered lava and/or pyroclastic, with minor magnetic highs due to small domes, plugs and magnetic lava flows
QLdd	Magnetic (high) andesite lava domes and/or high level intrusives, some with K-alteration haloes or associated zones
Pliocene Susungdalaga Volcanics	
PSvc	Area of radiating magnetic (high) flows, ? around older volcanic center
PSvm	Magnetic (high) volcanic, composite unit with dipping sheets, probably andesite
PSvn	Weakly to non-magnetic weathered and/or altered volcanic including pyroclastic, relatively homogeneous magnetic character
PSvr	Similar to PSvn but remanently magnetized, i.e. weakly to non-magnetic weathered and/or altered volcanic including pyroclastic, relatively homogeneous magnetic character
PSvh	Heterogenous volcanic unit, including horizons with remanent magnetization
PSva	Pervasively altered volcanic, expressed as subdued magnetic response and associated high K signature
Pliocene Macogon Formation	
PMm	Volcanic-dominated unit with moderate to high degrees of magnetization, high-frequency anomalies due largely to normally magnetized bodies, NW trends with cross cutting NE-trending dykes, moderate to high Th response
PMmm	Volcanic unit with moderate magnetic response, NW trends, moderate to high Th response
PMa	Magnetite-depleted corridors associated with NW faults

Map Unit Code	Description
Miocene Bosigon Formation	
MBm	Moderate to high magnetic response due to basaltic units, high K due to sedimentary component?, NW trends, cut by NE-trending dykes
MBn	Altered magnetite-depleted zones
Cretaceous Tigbinan Formation	
KTm	Volcanic (basaltic) bearing unit with linear magnetic anomalies (moderate) and low potassium
KTmk	Mixed volcanic-sedimentary unit with linear magnetic anomalies (moderate) and variable to high potassic response, alteration produces variable response
KTn	Subdued magnetic response associated with sedimentary dominated sequence
KTnk	Subdued magnetic response associated with sedimentary dominated sequence similar to KTn, but with higher K response

2-3 Summary

The correlation between physical characteristics got by airborne survey and the factors related to mineralization and deposit, is summarized below. The expected areas are mentioned.

Nalesbitan Prospect, a high sulfidation epithermal gold deposit, represents the only significant known mineralization in the area. It is characterized by an association with northwest trending faults, with mineralization possibly being focused in dilational zones within these faults, and a halo of argillized alteration expressed as high potassium in the gamma-ray spectral data.

Important factors in the exploration for epithermal mineralization (White and Hendenquist, 1990) are as follows:

- distribution of intrusives deep below the surface to provide heat for meteoric water circulation and to contribute magmatic components to the system
- presence of favorable structural settings –mineralization is commonly on subsidiary structures rather than the prominent regional features
- presence of extensive areas of alteration as these are commonly associated with the upper levels of geothermal systems, and, in particular, which associated with expected structures
- geochemical anomalism

Geophysical data can be used to identify several of these parameters especially at a regional scale, however detail prospect evaluation e.g. outlining specific ore hosting alteration and structures, may not be expected as these represent only a small part of the alteration system.

By using Nalesbitan Prospect as a case study, the interested areas are considered to be those showing a combination of northwest trending structures and alteration expressed as high potassium in the gamma-ray spectral data. In addition, Sillitoe et al (1990) described a pyroxene andesite plug or dome at the southeast of the mineralization. The body seems to be too small to identify with certainty in the magnetic data, however, potentially larger plug- type intrusives are present at the northeast of the mineralization.

To the east of Nalesbitan, potassic alteration centered on Salobosogin-Yakalan alteration, has a strong structural control, with both northwest and northeast trending faults. The northwest control, at the proximity to Nalesbitan, and the presence of an interpreted intrusive approximately 1 km to the north (indicative of intrusive activity in the area rather a specific mineralized body) suggest that the zone has some potential.

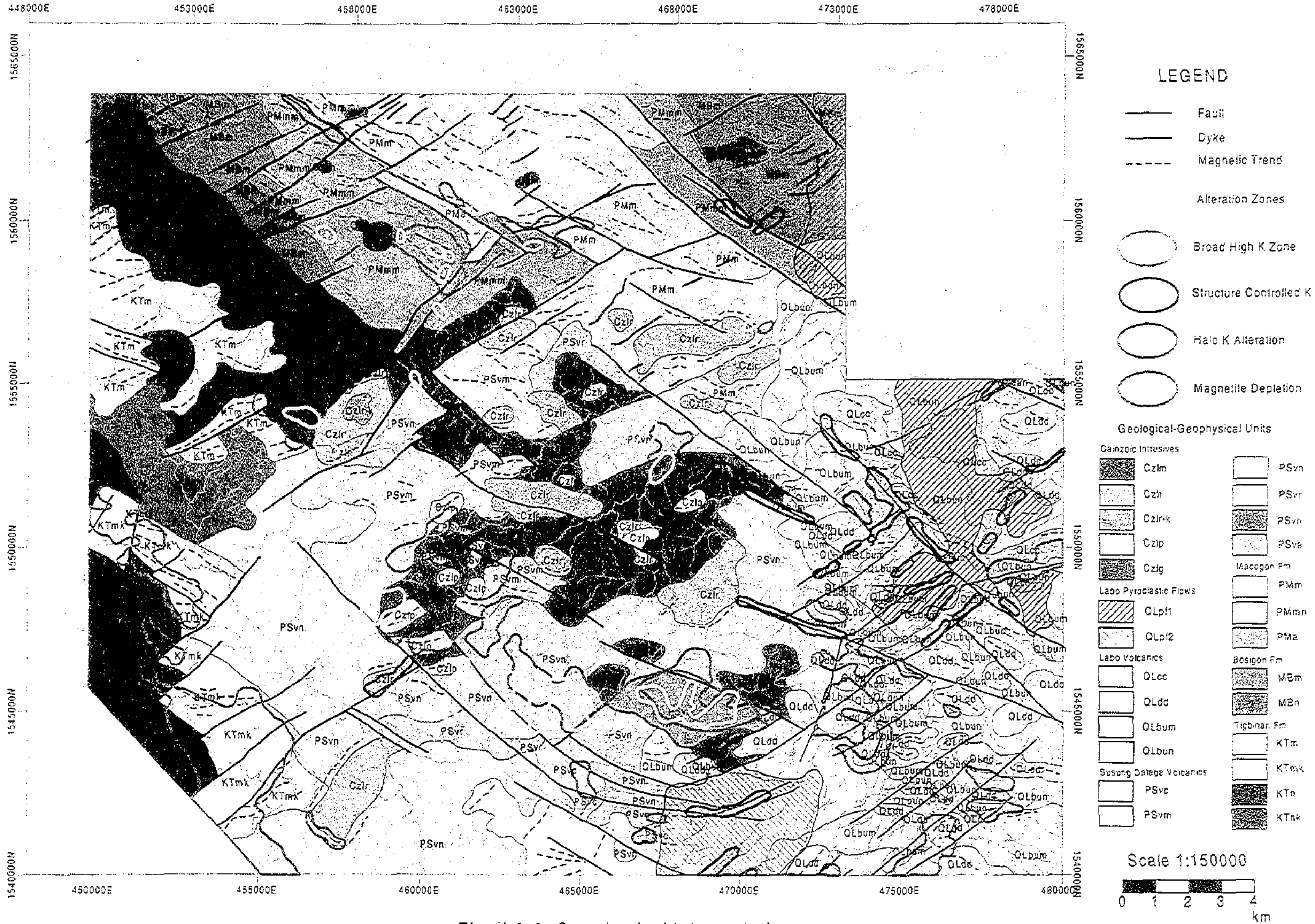


Fig. II-2-8 Geophysical Interpretation

A broad potassic high at the southwest of Nalesbitan in Katakian alteration zone is associated with northeast trending faults rather than northwest trending, but is proximal to major intrusive bodies.

Another main interested area is the northwest trending regional corridor of zones of alteration zones extending from Alawihaw – Kilbay Creek area to Tonton River area. The northwestern end of the corridor is potentially the most interested area due to the presence of a number of intrusives determined by geophysical survey. The result shows the alteration outlined anomalous gold and copper, and also indicates the alteration that is much more extensive than it by the geological mapping, thus increasing the potential of the area.

Alteration systems on Mt. Labo are part of currently and recently active geothermal systems. The alteration is currently focused along fault systems in which the geothermal systems are upwelling. Minor base metal geochemical anomaly is present at depth. The current level of exposure is upper portion of the geothermal system. The alteration zone seems to be insufficiently exposed by lesser erosion at the level. The dominance of the expression of shallow sourced high frequency anomalies in the magnetic data means that any deeper intrusives may be driving the current geothermal systems of Mt. Labo, cannot be readily delineated.

The nature of high potassic zones in older sediments in the west of the area is uncertain. Potentially high-K-anomaly may represent alteration systems in a distance from former eruptive centers in Susungdalaga Volcanics, although there are no indications in the magnetic data of coeval intrusives which may have driven the hydrothermal system.

Chapter 3 Geochemical Survey

3-1 Method

The stream sediments samples were collected at main rivers and the tributary. Samples were taken by 30 mesh sieves in the field and stored into craft bags. At the base-camp, after drying, the samples for BLEG analysis were shipped without sieving after drying and the samples for the ordinary geochemical analysis were sieved by 80 mesh sieve, and shipped to the laboratory.

The results of chemical analysis are shown in the report of Phase-II.

For the interpretation, the classification was made by means of the histogram and the accumulated histogram distribution curve of assay results. The correlative coefficient among elements were calculated, and the the distribution of each indicative element which are related to Au-Cu were shown on the map. For the correlation matrix calculated from logarithm of analysis values of soil samples, principal components values are calculated.

3-2 Geochemical Interpretation on Stream Sediments

3-2-1 BLEG analysis

The histograms and probability plots of Au and Cu values are shown in Fig.II-3-1. Threshold values of Au and Cu are 10 ppb and 0.5 ppm respectively.

[Au] The high Au values are concentrated in the drainage areas of Nalesbitan and Tuba gold deposits. It might reflect the contamination of present small-scale mining activity. Other anomaly values are associated with Alawihaw alteration zones in the south of the survey area. Au values ranging from 2 to 4 ppb are shown in Alawihaw and Kampusta alteration zones which are slightly high values.

[Cu] The high Cu values are concentrated in the drainage area of Nalesbitan and Tuba gold deposits. It might reflect the contamination of present small-scale mining activity. And the broad area is concentrated in Kilbay valley.

3-2-2 Geochemical Survey on Stream sediments

In general, geochemical analysis value, especially minor elements, show the similar value of the regular logarithm distribution when the analysis accuracy is reliable and mother group is single.

A common logarithm value of each analysis value is used for data processing. As for an analysis value lower than detection limit value, a half of that value is adopted in the statistical processing. Also as for an analysis value higher than a maximum detection limit value, the limit value is adopted. In order to decide the threshold that sorts out the anomaly from the background level of geochemical data. In this report, the combination of the average and the standard deviation is taken as the criterion. However, the inflection point and the natural gap are also considered for the decision.

The elements associated with Au and Cu mineralization are expected high positive correlation with Au and Cu. These elements are Au, Ag, As, Cu, Hg, Mo, Pb, S and Sb. The threshold of each element is Au: 42ppb, Ag:0.31ppm, As:26ppm, Cu:67ppm, Hg:290ppb, Mo:5.8ppm, Pb:6.7ppm, S:0.14%, Sb:3.8ppm. Therefore the distributions of these elements are shown in Fig.II-3-2~II-3-6.

The anomaly value distribution on each element is mentioned below.

[Au] The samples with extremely high Au content concentrate in the area around Nalesbitan and

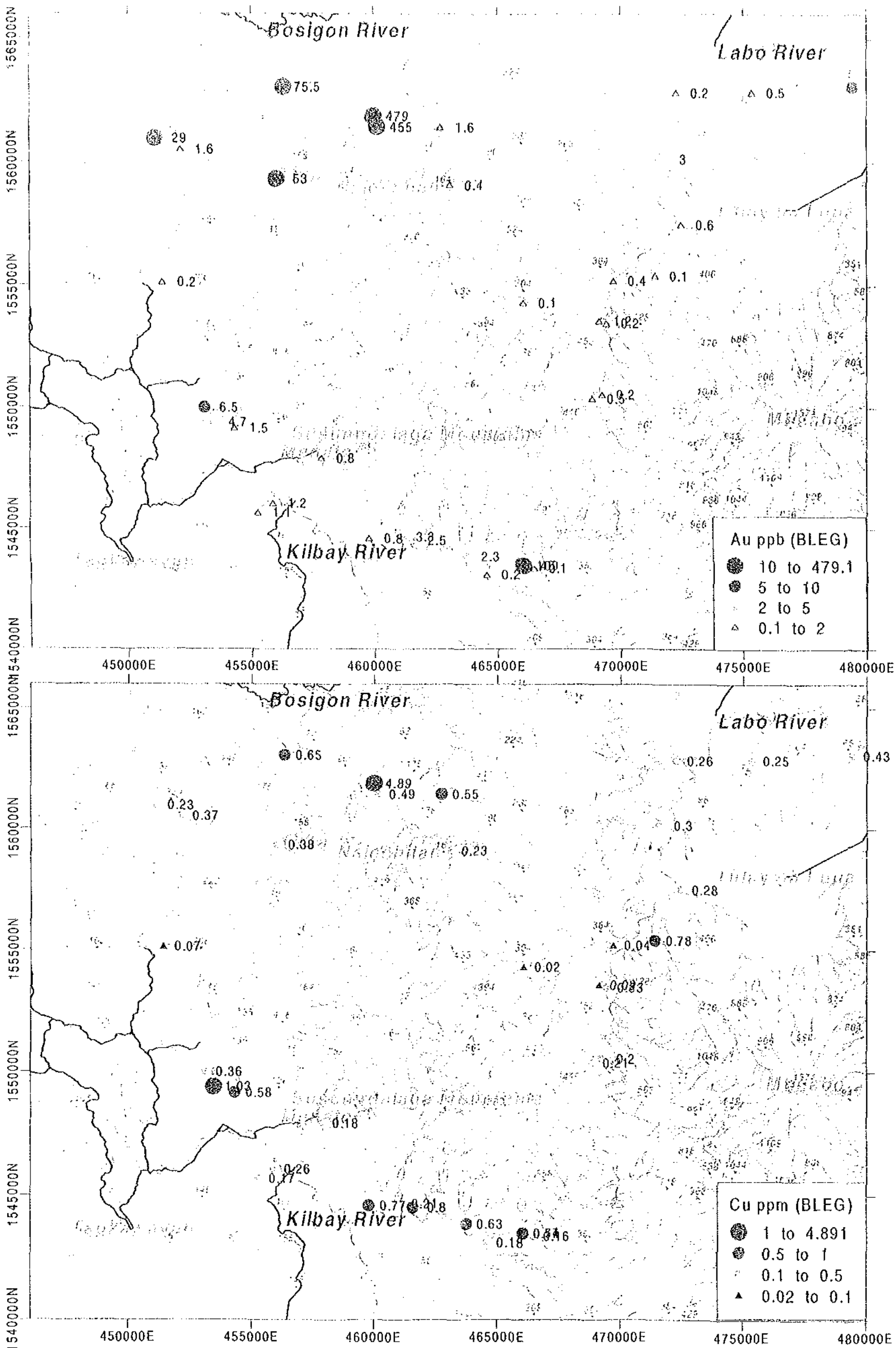


Fig. II-3-1 Au and Cu Content of the BLEG Samples

Tuba mineral occurrences. Alawihaw alteration zone in the upper part of Kilbay River and the Katakian alteration zone at the south of Tuba is also the areas with high gold content.

[Ag] The anomaly is concentrated in comparatively smaller area than it of Au. It is confined only the area around Nalesbitan and Tuba mineral occurrences.

[As] The samples with high As content concentrate in the area around Nalesbitan and Tuba mineral occurrences. The anomaly zone extends eastward to Salobosogin-Yakalan alteration zone at the east of Nalesbitan. Alawihaw alteration zone is also the area with high As content. The anomaly values are scattered in Maniknik alteration zone in the western tributary of Kilbay River, and Magasawang-Bato and Taktak alteration zones in the upper stream of Labo River.

[Cu] The area with high Cu content is only confined in the area around the Nalesbitan mineral occurrences. The only one anomaly value is found in Tuba occurrences. It indicates the mineralization is limited. A cluster of anomaly values is detected 4 km in the east of Nalesbitan. And Katakian alteration zone also has anormaly value.

[Hg] The samples with high Hg content concentrate in the area around Nalesbitan and Tuba mineral occurrences. Some anomaly values are found in the upper stream of Kilbay River and upper stream of Labo River.

[Mo] The samples with high Mo content concentrate in Nalesbitan area and Maniknik alteration zone.

[Pb] The samples with high Pb content concentrate in Nalesbitan area, the northern part of Katakian alteration zone, and the upper part of Kilbay River from Alawihaw to Katigbigan zone. The anomaly zone is also detected in Magasawang Bato alteration zone in Labo Valley.

[S] The sulfur content reflects directly the quantity of sulfide minerals. The high sulfur zones are delineated in Nalesbitan-Tuba area, Katakian alteration zone, the area from Alawihaw to Katigbigan zone, the area from Layaton Malaki to Maniknik, and Kampusta alteration zone.

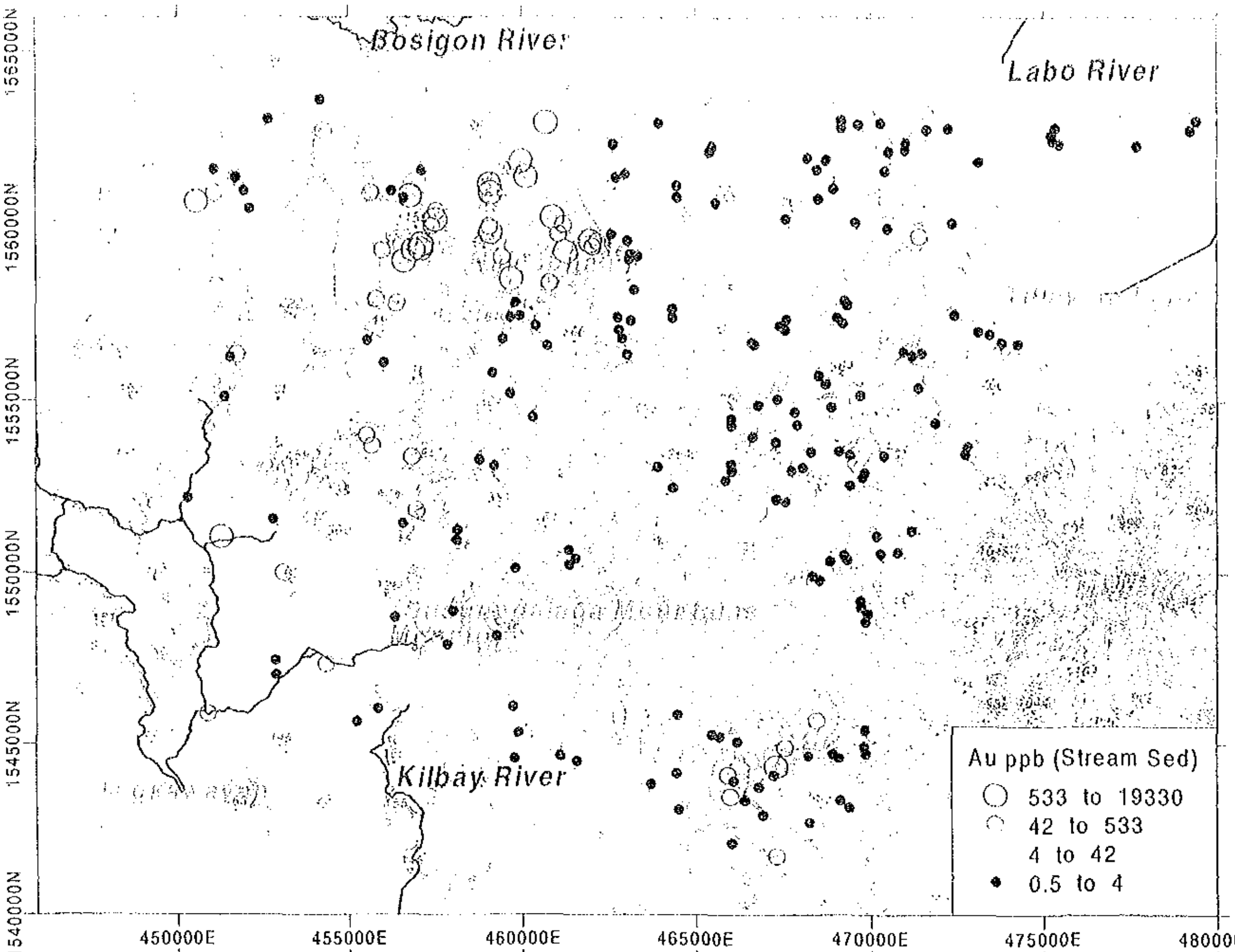
[Sb] The samples with high Sb content concentrate in Nalesbitan area. Other high values are scattered in the upstream of Labo River.

For the correlation matrix calculated from logarithm of analysis values of stream sediments samples, principal components values are calculated.

Eigenvalues of up to the fourth principal components are above 2. Cumulative contribution up to the fourth principal components is 68%. The score distribution are shown in Fig.II-3-8～II-3-9. The summary of result is mentioned below.

[Z-01] The factor loadings of Mn, Co, Sc, Ti, V, Al, Ca, Cr and Sr relating to the first principal components, are highly positive. They are considered the correspondence to lithofacies of the survey area. Those of Au, Ag, As, Sb, Mo and Bi are negative. They are all indicative elements of epithermal mineralization, therefore it can be interpreted that the negative score represents a mineralization. The areas with negative scores are around Nalesbitan and Tuba deposits, Katakian alteration zone, Alawihaw～Katigbigan alteration zone,and Layaton Malaki～Maniknik alteration zone. Katakian alteration zone may become the source of a broad anomaly toward the dounstream of the river.

[Z-02] The second principal components contribute 20% of original variability. The factor loadings of Cu, As, Sb, Hg, P, Pb, Zn and Fe relating to the second principal components, are highly positive; therefore, it may indicate the Cu related mineralization. The areas of positive scores are around Nalesbitan and Tuba deposits, Katakian alteration zone, Alawihaw～Katigbigan alteration zone,



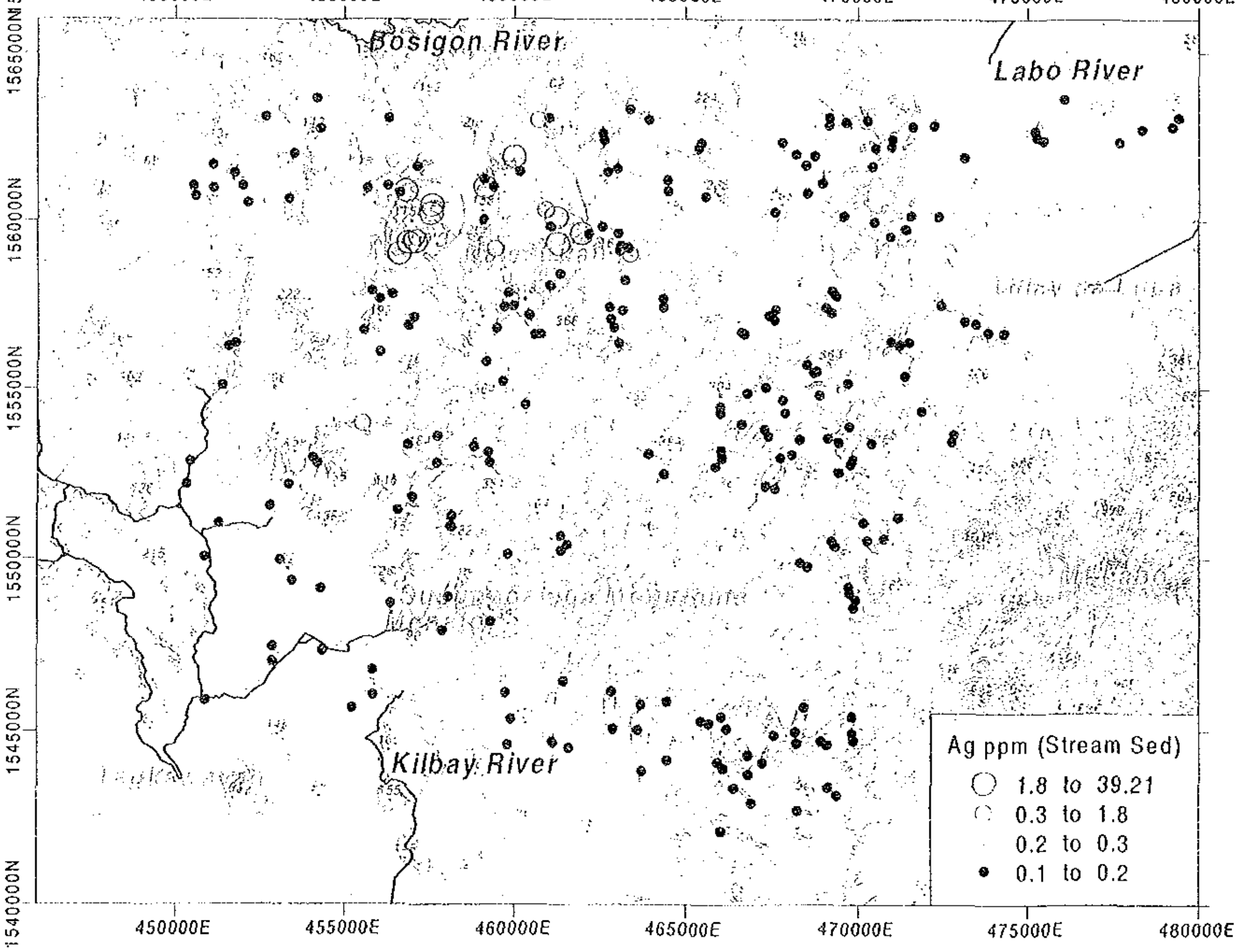
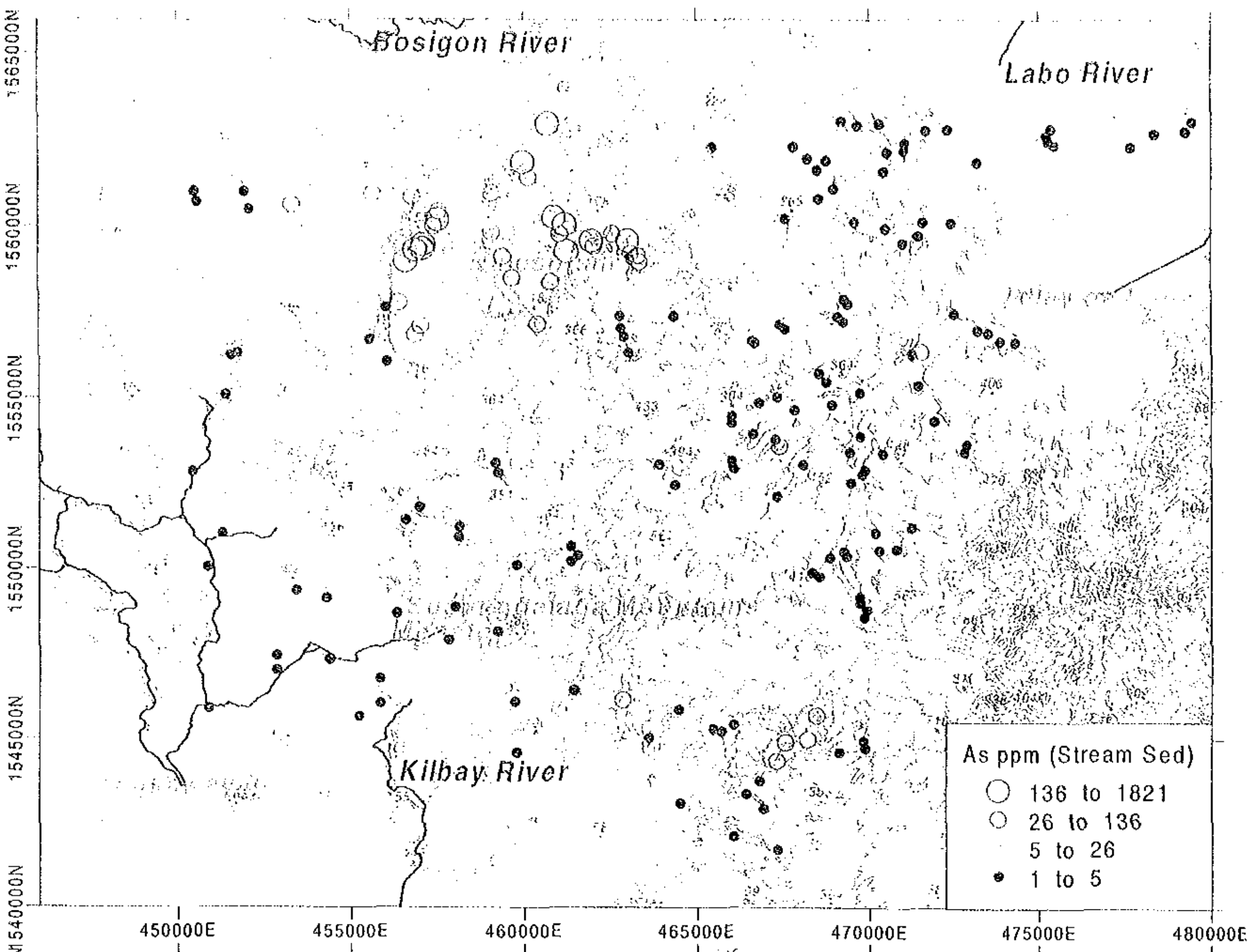


Fig. II-3-2 Au and Ag Content of the Stream Sediments Samples



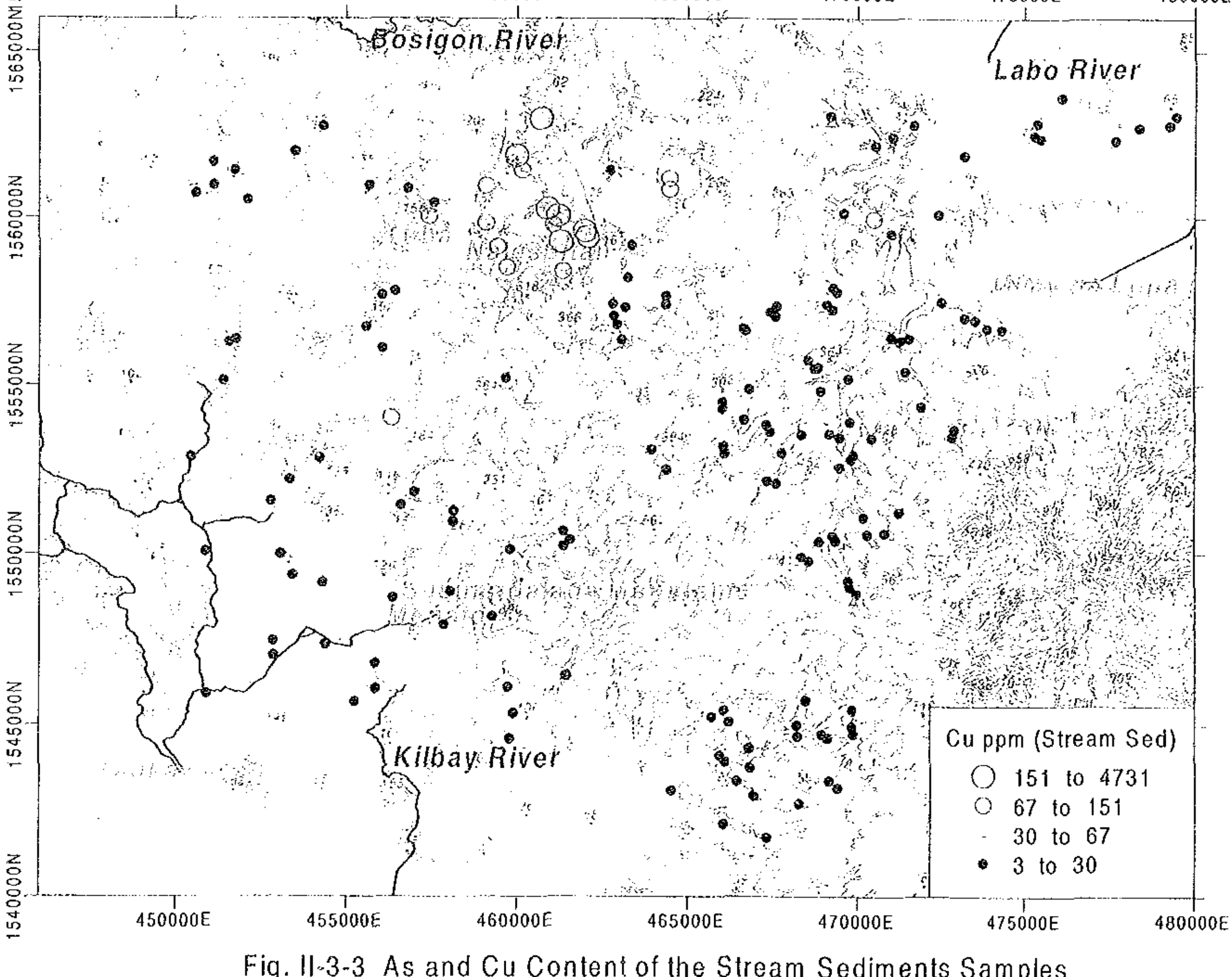
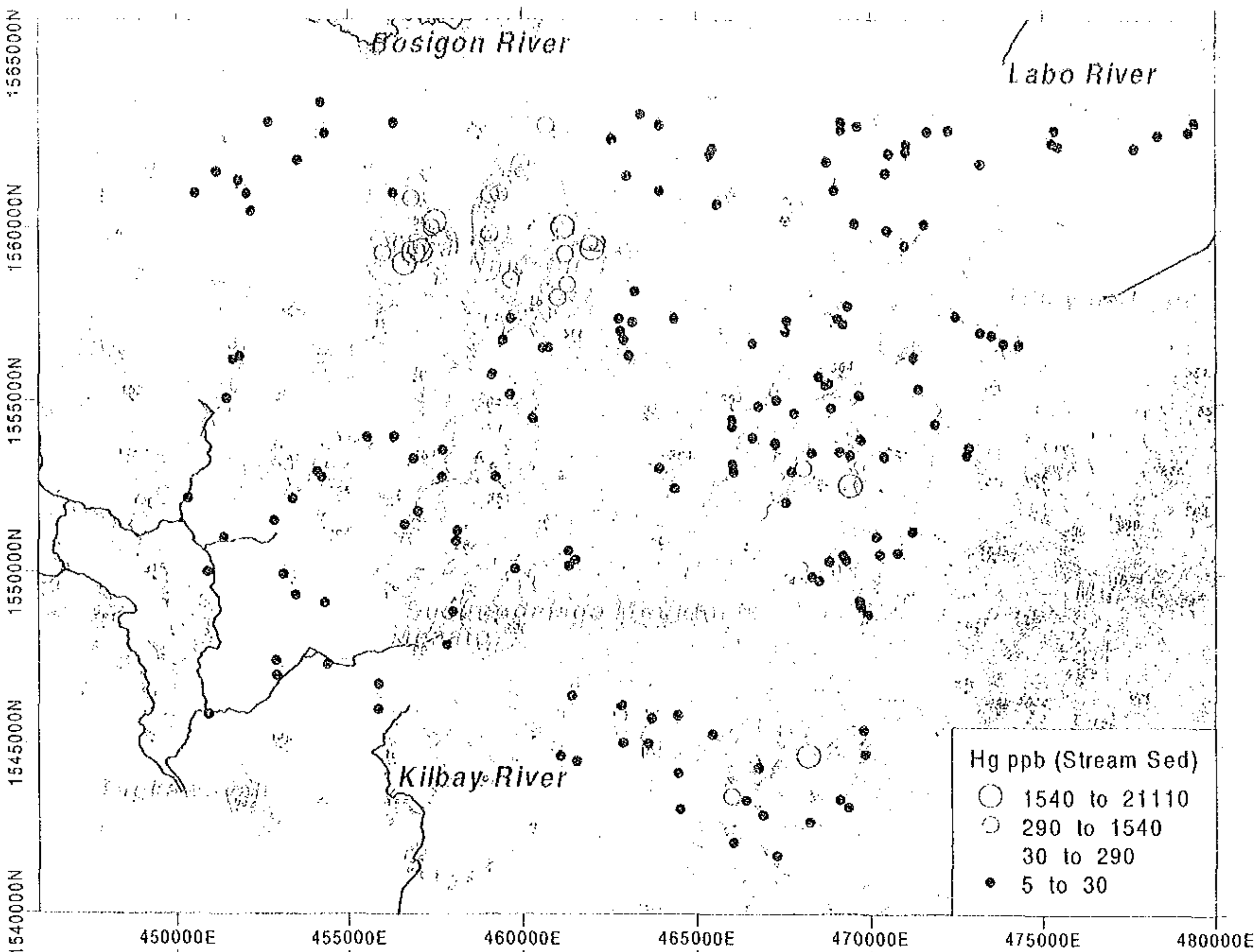


Fig. II-3-3 As and Cu Content of the Stream Sediments Samples



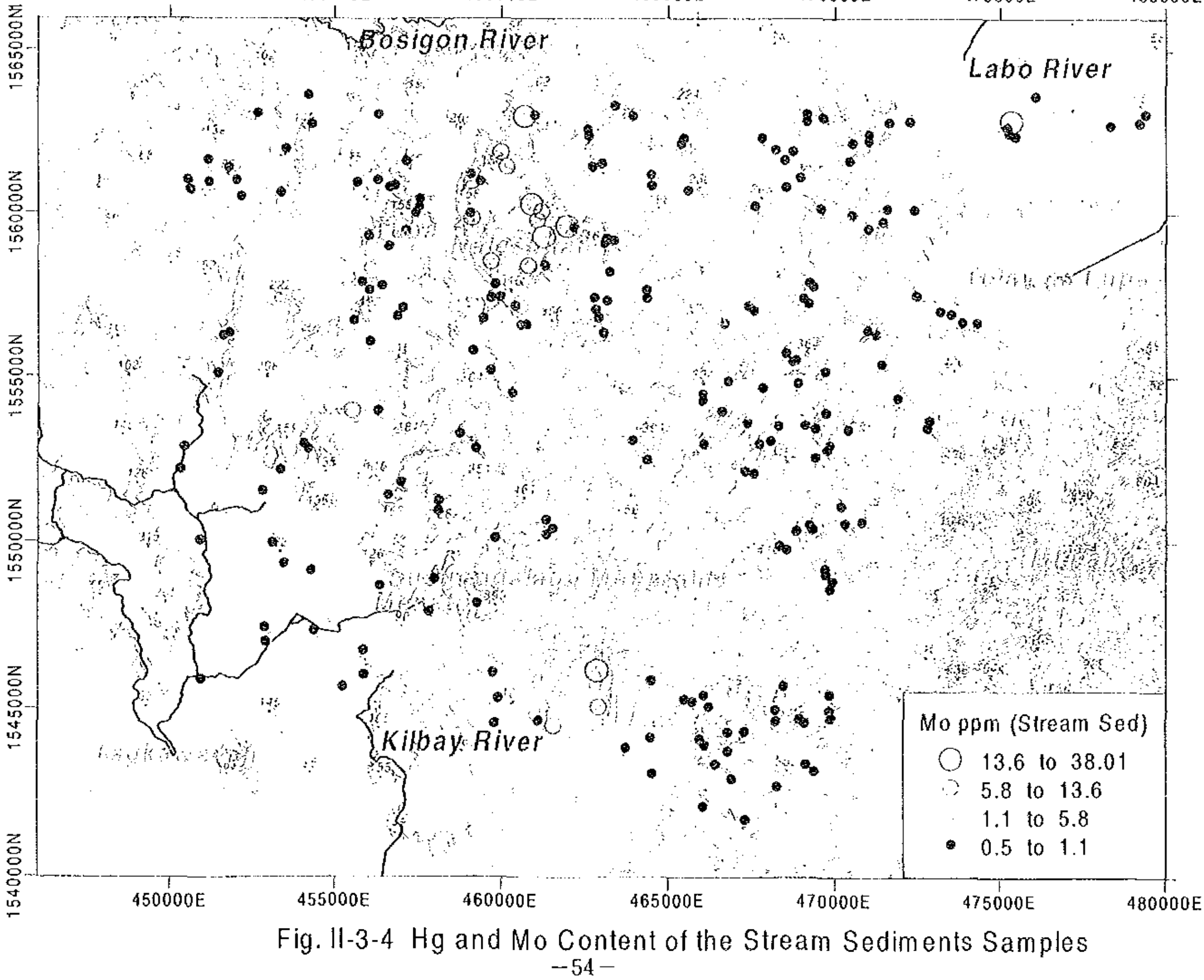


Fig. II-3-4 Hg and Mo Content of the Stream Sediments Samples

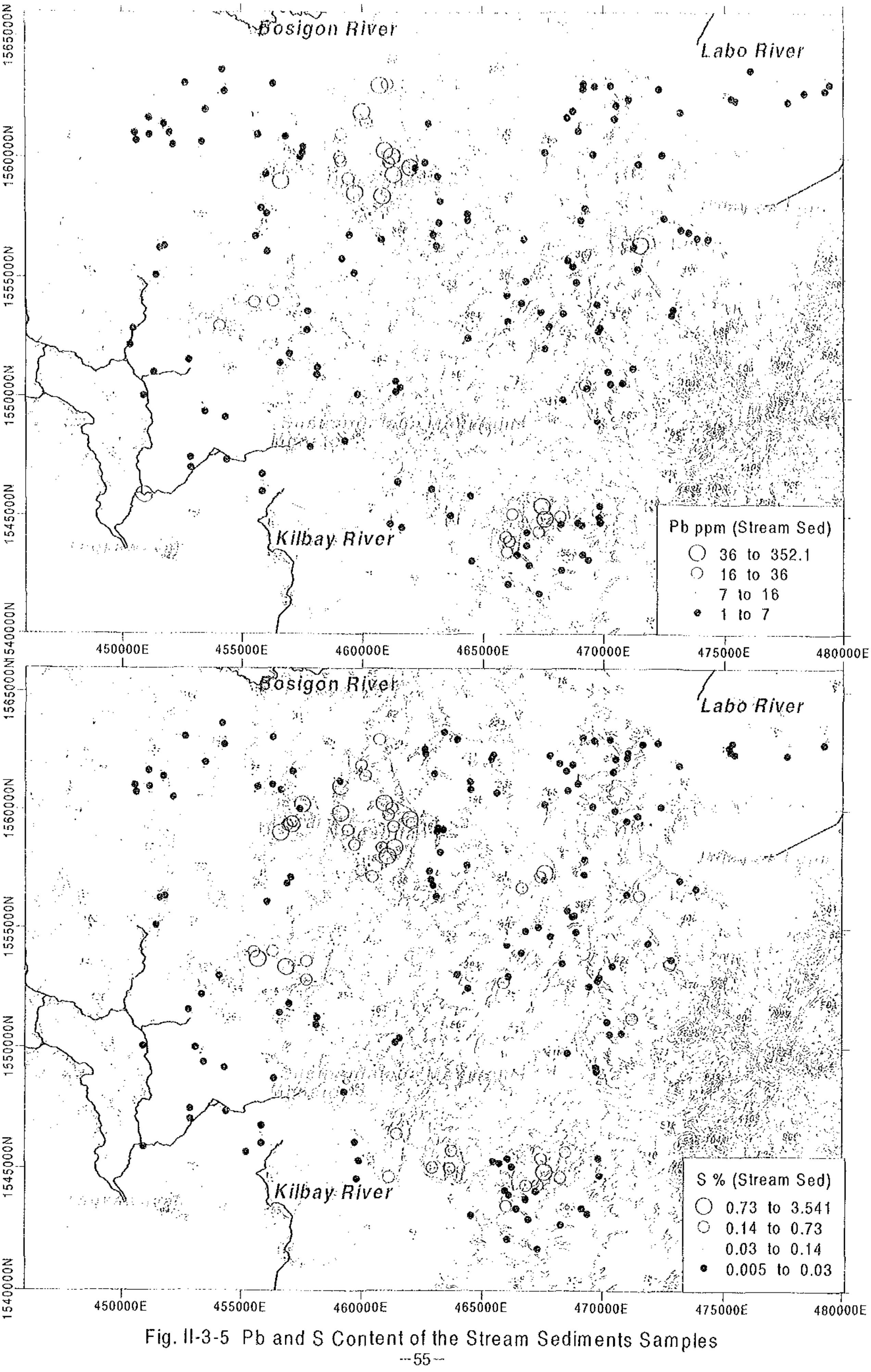


Fig. II-3-5 Pb and S Content of the Stream Sediments Samples

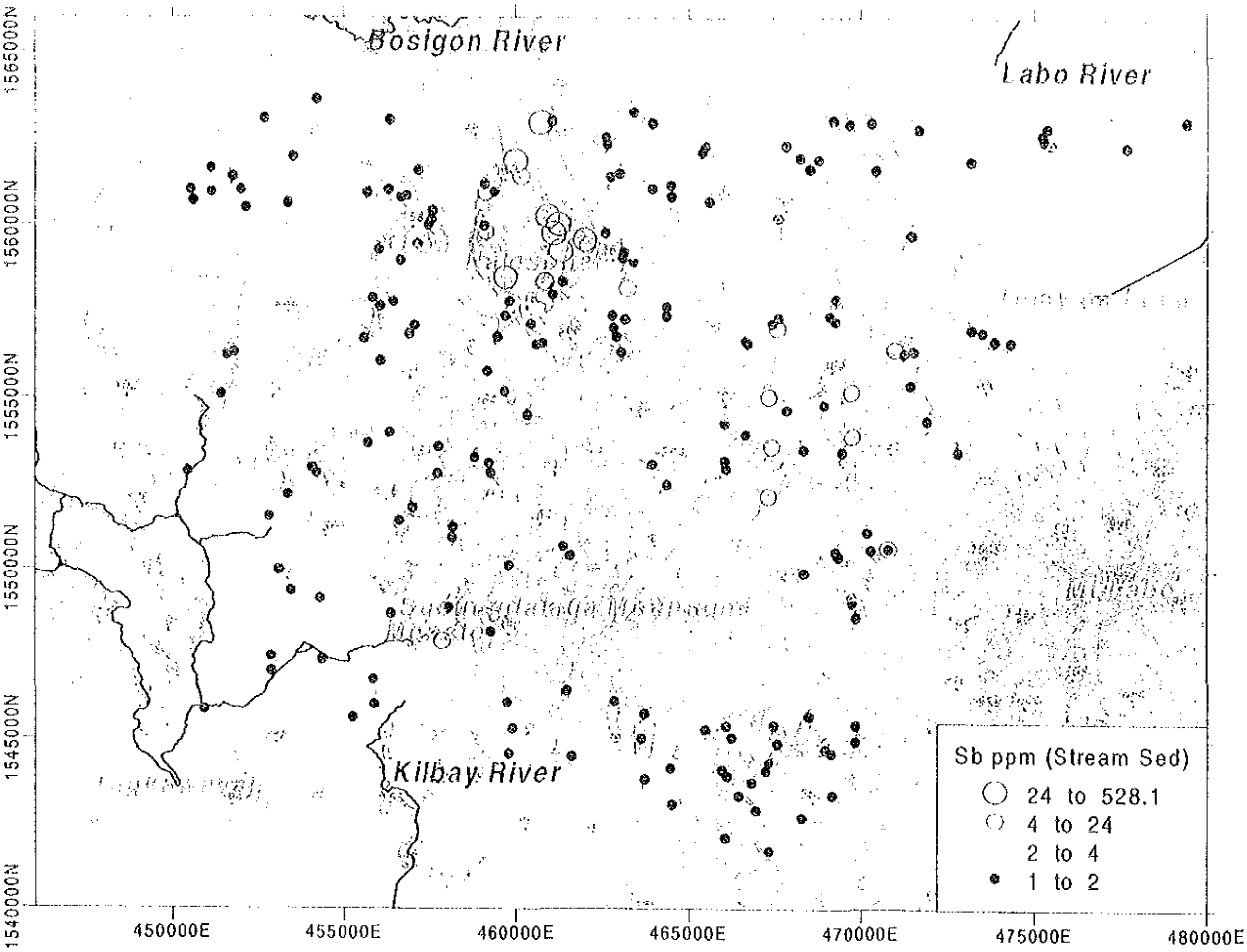
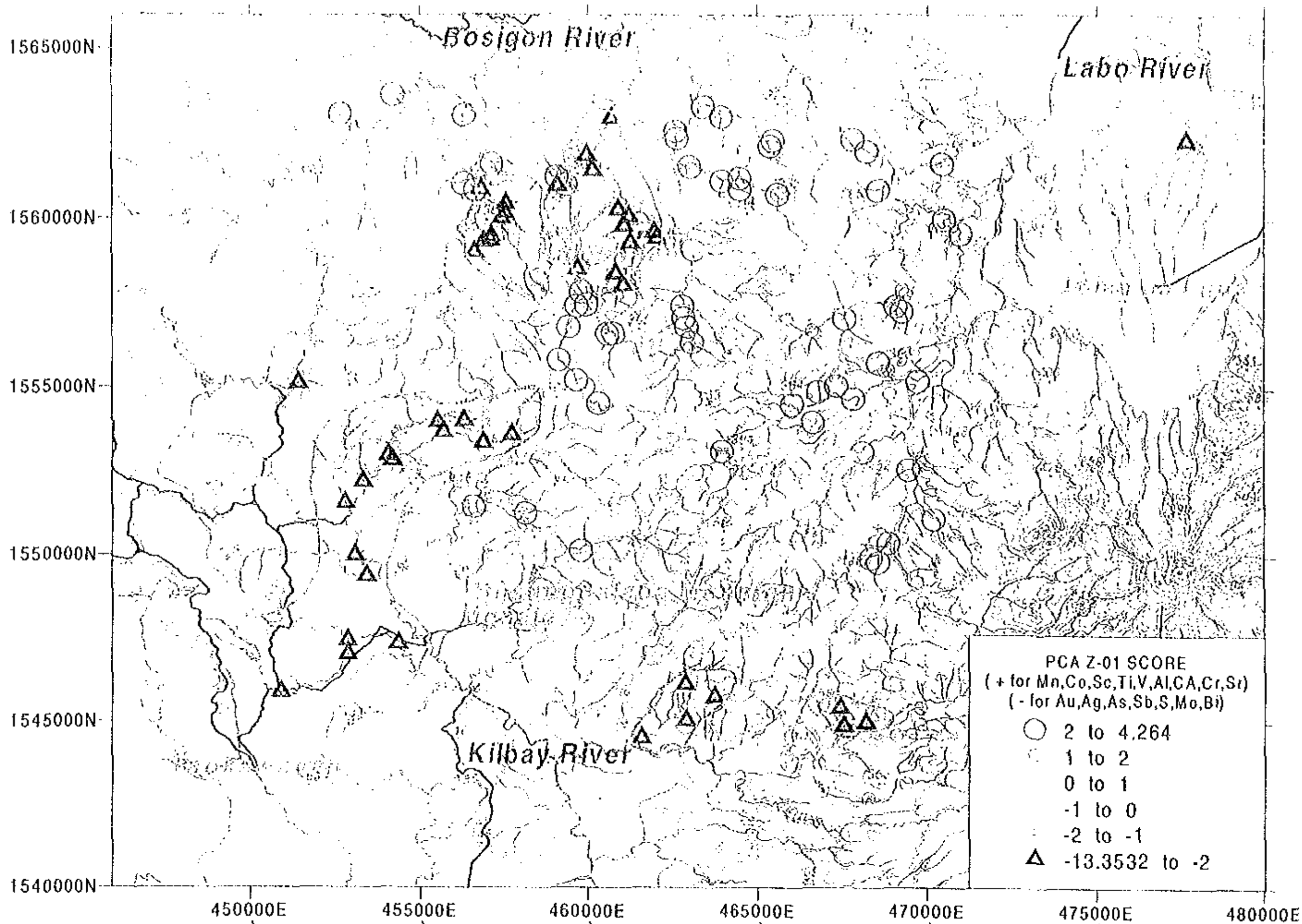


Fig. II-3-6 Sb Content of the Stream Sediments Samples



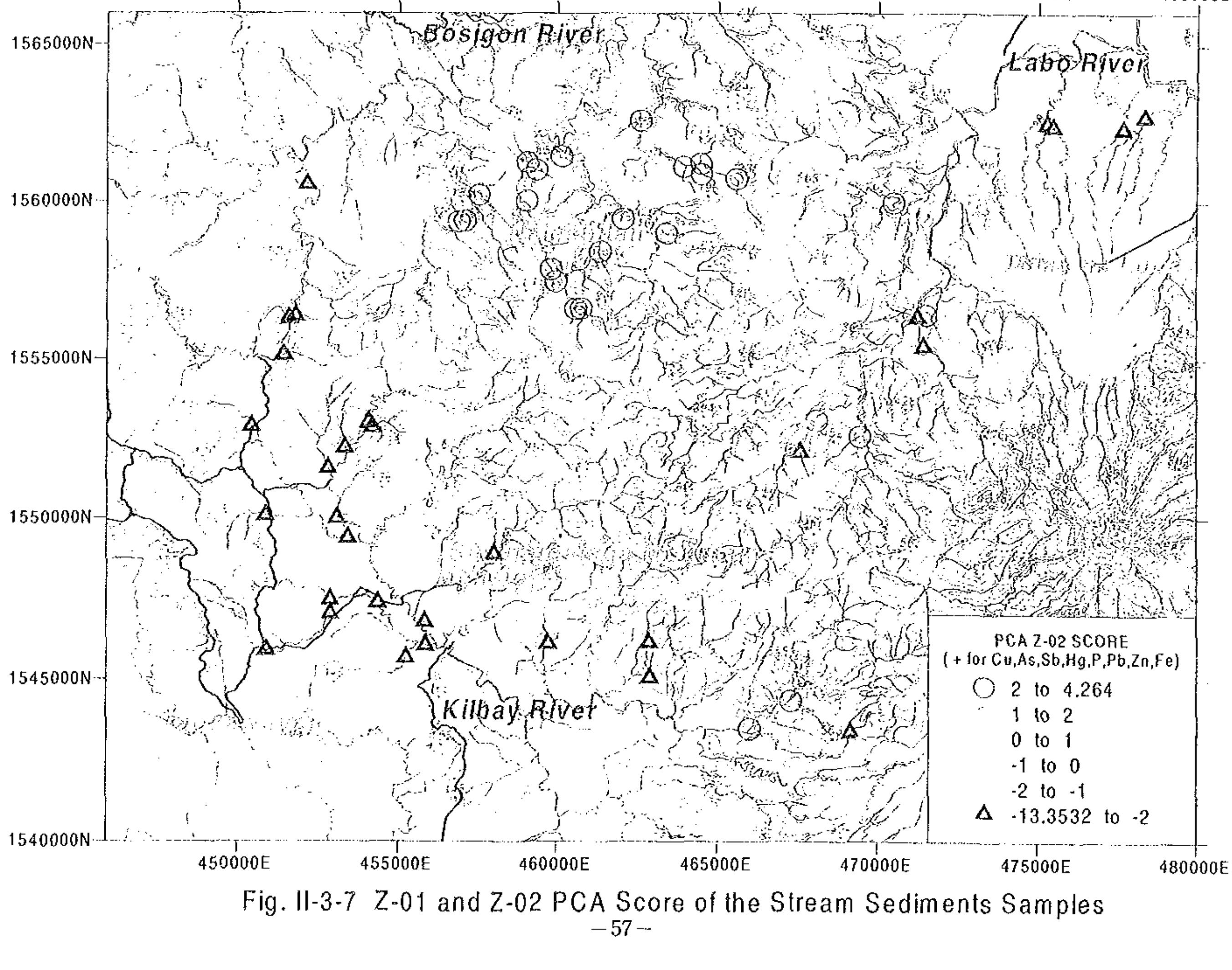


Fig. II-3-7 Z-01 and Z-02 PCA Score of the Stream Sediments Samples

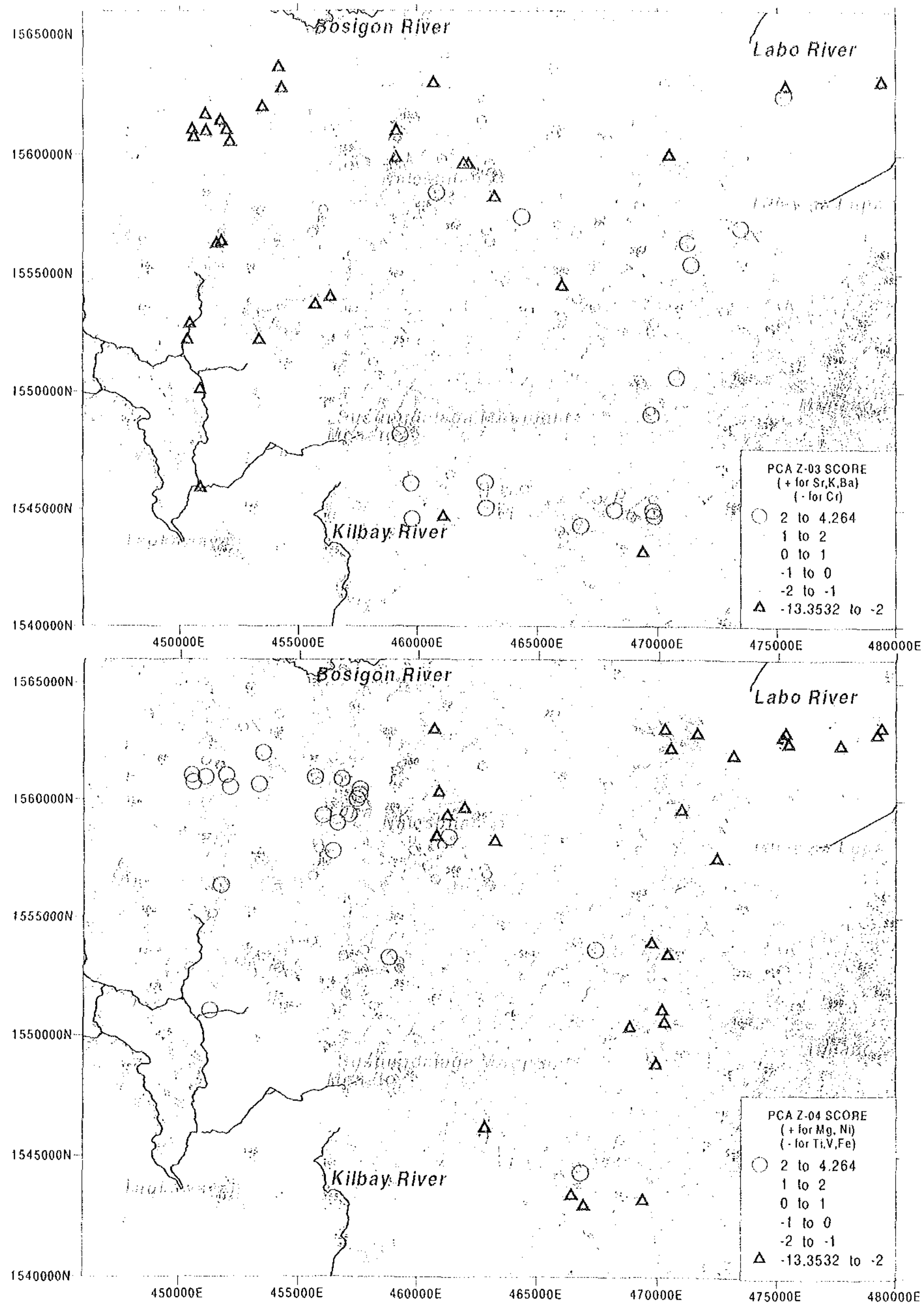


Fig. II-3-8 Z-03 and Z-04 PCA Score of the Stream Sediments Samples and Magasawang Bato and Binangkawan alteration zone in Labo Valley.

[Z-03] The third principal components contribute 10% of original variability. The factor loadings of Sr, K and Ba relating to the third principal components, are positive, while that of Cr is negative. The negative of third principal components is in west of the area because of the existence of ophiolite sequence.

[Z-04] The fourth principal components contribute 9% of original variability. The factor loadings of Mg and Ni relating to the fourth principal components, are positive, while those of Ti, V and Fe are negative. The area of positive scores is in the northwestern part, while that of negative scores is in the eastern part around Labo Valley. The elements may largely explain the lithofacies of the area.

3-3 Summary

The geochemical anomaly zones of each element are superimposed in Fig.II-3-9.

The Au anomaly values of the stream sediment samples are recognized in the following areas: Nalesbitan-Tuba mineral occurrences, Katakian alteration zone and Alawihaw alteration zone. Even if the contamination of mining activity is considered, the original anomaly may also extend widely around Nalesbitan.

The sulfur anomaly zones, which may correspond to sulfide ore in the alteration zone, are outlined in Nalesbitan, Tuba, Katakian, the area around Alawihaw, Layaton-Maniknik, and Kampusta alteration zones.

Mo anomaly zones are delineated in Nalesbitan area and Maniknik alteration zone. The deposits containing Mo suite are characteristic of the upper part of porphyry Cu system. The Mo anomaly in Maniknik may indicate the existence of the same type mineralization as Nalesbitan.

The anomalies of mobile elements such as Sb, As and Hg are often characterized the upper part of the epithermal systems. The anomaly values concentrate in Nalesbitan, Tuba and the area around Alawihaw. The anomaly in Nalesbitan extends eastward to Salobosogin-Yakalan alteration zone. It may indicate the undiscovered Nalesbitan-type mineralization zone in the area. The anomaly values of Sb, As and Hg are scattered in the upstream of Kilbay River and the upstream of Labo River.

The score distribution of first principal components could outline the anomalies of Au related to indicative elements. The areas are Nalesbitan, Tuba, Katakian, Maniknik-Layaton, and the area around Alawihaw. The anomaly of Katakian alteration zone broadly extends to downstream in particular.

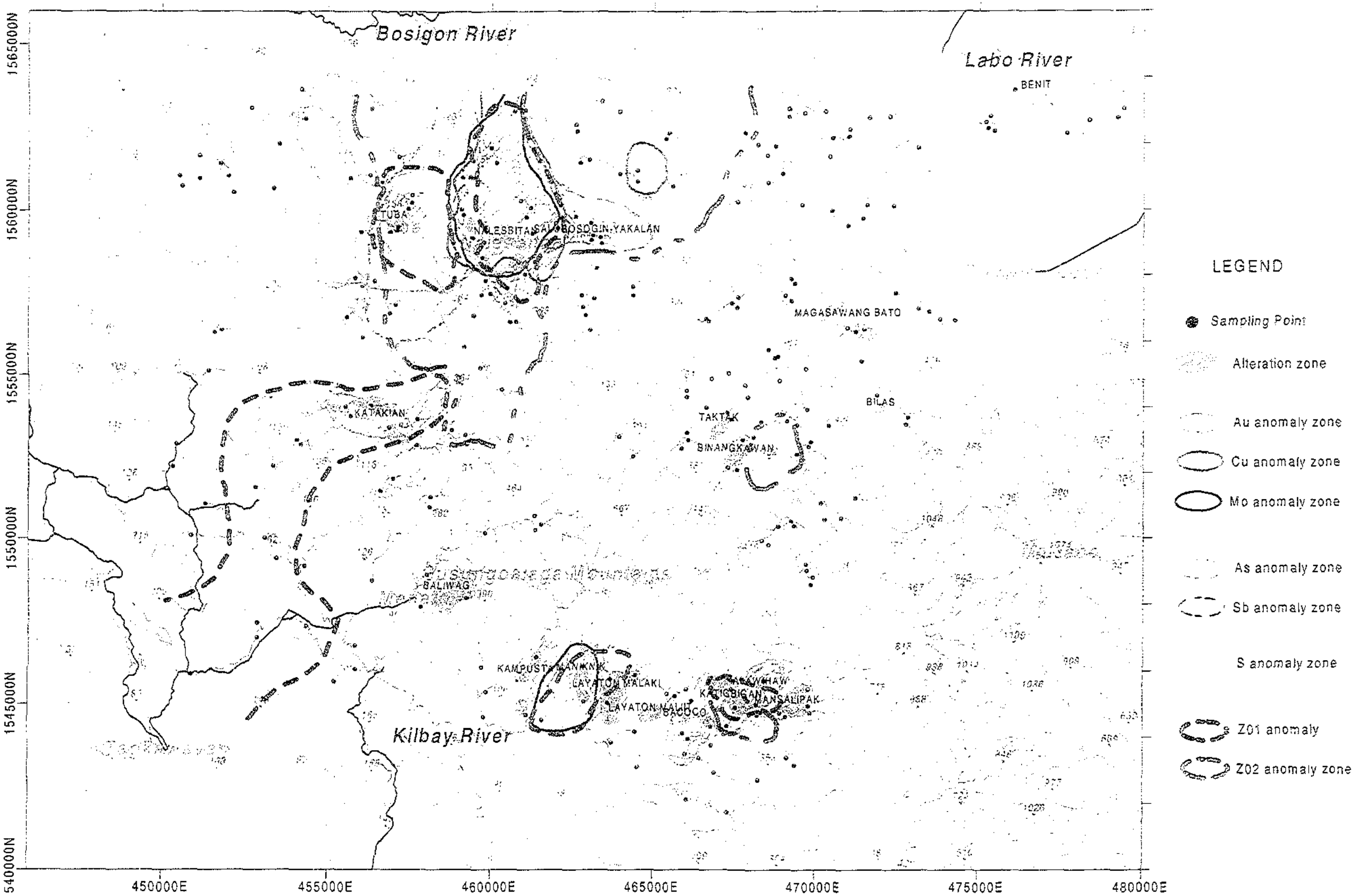


Fig. II-3-9 Distribution of Geochemical Anomaly of Stream Sediments Samples