REPORT
ON
THE GEOLOGICAL SURVEY
IN THE URUBAMBA RIVER INTERIOR AREA
OF
THE REPUBLIC OF PERU

(PHASE I)

MARCH 1990

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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PREFACE

In response to the request of the government of the Republic of Peru, the Japanese government determined to conduct a series of survey related to exploration of ore deposits including analysis of the existing data and satellite image analysis, for the purpose of examining the potentials of mineral resources in the Urubamba river inferior area of the Republic, and entrusted the survey to the Japan International Cooperation Agency (JICA). In view of the geological and mineralogical nature of the intended survey, the JICA commissioned the Metal Mining Agency of Japan (MMAJ) to implement the survey. The survey started in FY1998 (Phase I), and the MMAJ organized and sent a two-man survey team to the Republic of Peru for the period from January 24 to February 13, 1999.

The field survey was completed as scheduled, in close collaboration with, the Peruvian government agency, the Institute of Geology, Mineralogy and Metallurgy (INGEMMET) under the Ministry of Energy and Mines.

This report summarizes the results of the first year's survey and is designed to form an integral part of the final survey report to be elaborated.

We should like to take this opportunity to express our sincere gratitude to the Peruvian government agencies and persons concerned for their valuable cooperation. We are also thankful to the Japanese Ministry of Foreign Affairs, the Ministry of International Trade and Industry, the Embassy of Japan in Lima and persons concerned who have rendered assistance and support for the survey.

March, 1999

Kimio Fujita
President
Japan International Cooperation Agency

Hiroaki Hiyama
President
Metal Mining Agency of Japan

THE GEOLOGICAL SURVEY
IN THE URUBAMBA RIVER INFERIOR AREA,
THE REPUBLIC OF PERU

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Summary

This report describes results of the first year's survey in FY1998, implemented in the Urubamba river inferior area of the Republic of Peru, under the technical cooperation for the mineral exploration. The survey was conducted with an aim to effectively select promising zones from the extensive survey area in a short period of time, by means of satellite image analysis, existing data analysis and integrated studies of survey findings of an area upstream of the Amazon in eastern Peru, which covers the Ucayali River Basin and its upper streams, the Urubamba and the Tambo, where the metallogenic zoning has not been clarified in detail. Simultaneously, the technology transfer to the INGEMMET - Instituto Geológico Minero y Metalúrgico, the Peruvian counterpart for the survey, was carried out concerning the methods of survey and analysis. Collection and analysis of existing data and the satellite image analysis for the purpose of the technology transfer was executed from January 24 to February 23, 1999.

The Urubamba river inferior area covers an area of about 65,500 km^2, spreading over the 28 quadrangles of the 1:100,000-scale topographic map issued by the National Geographical Institute of Peru. In Phase I, the analysis of the JERS-1 SAR images was conducted of the 15 quadrangles in the western part of the mentioned area, situated at 75° to 70°30' W of longitude and 11° to 9°30' S of latitude, whilst the existing data analysis was conducted of the entire Urubamba river inferior area.

The results of the Phase I survey are summarized as follows:

(1) As the analysis of the drainage patterns using JERS-1 SAR data of the Ucayali sedimentary basin, presence of anticlines or dome structures and possible presence of intrusive rocks were obtained. Of the eastern "Selva" (forest) zone of Peru, as represented by this interpretation area, the drainage analysis utilizing satellite images proved to be effective for interpretation of geology and geologic structure.

(2) The image analysis using the JERS-1 SAR data revealed the existence of high density zones of lineament in the NNW-SSE trending thrust zone in the east of Sira range, where many NNW-SSE lineaments supposed to be suggesting the presence of small-scale faults accompanying to the above mentioned thrust, and ENE-WSW lineaments possibly indicating tension fractures or strike-slip faults, were delineated. Tension fracture generally has a possibility to accompanied with intrusive rocks and/or hydrothermal activities related to intrusions. A hot spring related to NE-SW trending fault are known in Agua Caliente in the Northwest of the survey area. A high density zones of lineament in the east of Sira range, therefore, are considered to be important areas for mineral exploration.

(3) It was learned from the existing data analysis that the geological survey recently undertaken by INGEMMET ascertained presence of intrusive rocks

accompanied by gold and copper mineral indications 13 km east of Puerto Inca, which is included in the quadrangle 19-n of the 1:100,000-scale topographic map. Since the mineral indications and placer gold deposits in the Negro River in the quadrangle 20-n occur in the similar ambience in terms of geologic structure, the showings are likely to be a source (primary deposit) of placer gold deposits. Accordingly, it is possible that both primary and secondary (placer) gold deposits will be discovered by future systematic exploration.

(4) It has been reported that, in the Selva, gold and tin are contained in heavy minerals in the stream sediments along the Urubamba river near the tributary on the east bank of the Ucayali (20-o), Atalaya (Quad. 22-o) and Sepa (Quad. 22-p). A report says that, near Sepa, some panning sample of heavy minerals assays Au 1.6 g/t, which indicates a high possibility of occurrence of placer gold deposits. At present, small mining contractors seem to inactively engage in placer gold mining there. It is possible for minable placer gold deposits to be discovered by future surveys to the east of the Ucayali-Urubamba rivers, as well.

Based on the survey findings summarized above, the following recommendations may be made for the future survey:

(1) Satellite image analysis: Execute, in collaboration with the Peruvian engineers, the JERS-1 SAR data processing to prepare mosaic images covering the 13 quadrangles in the eastern part of the Urubamba river inferior area, in an effort to ensure the transfer of the SAR image processing technology in Peru. Successively, execute image interpretation including geologic mappings and lineament delineations, digitizing of interpretation results, preparation and analysis, such as lineament density mapping, of GIS data set.

(2) Analysis of existing data: Collect and compile additional data prepared in Peru after the Phase I survey (mainly information related with mining claims).

(3) Field survey: Consider the possibility to execute the field surveys aimed to ascertain mineralization, with the base camp at Atalaya, situated in the east foot of the Sira range where the Tertiary intrusive rocks are present and relatively close to the placer gold mineral indications in the Urubamba-Ucayali rivers. The survey will include the following items:

- Geochemical sampling of stream sediments, heavy minerals and rocks.
- Investigation of mineral indications.
- Verification of lithofacies along survey routes.

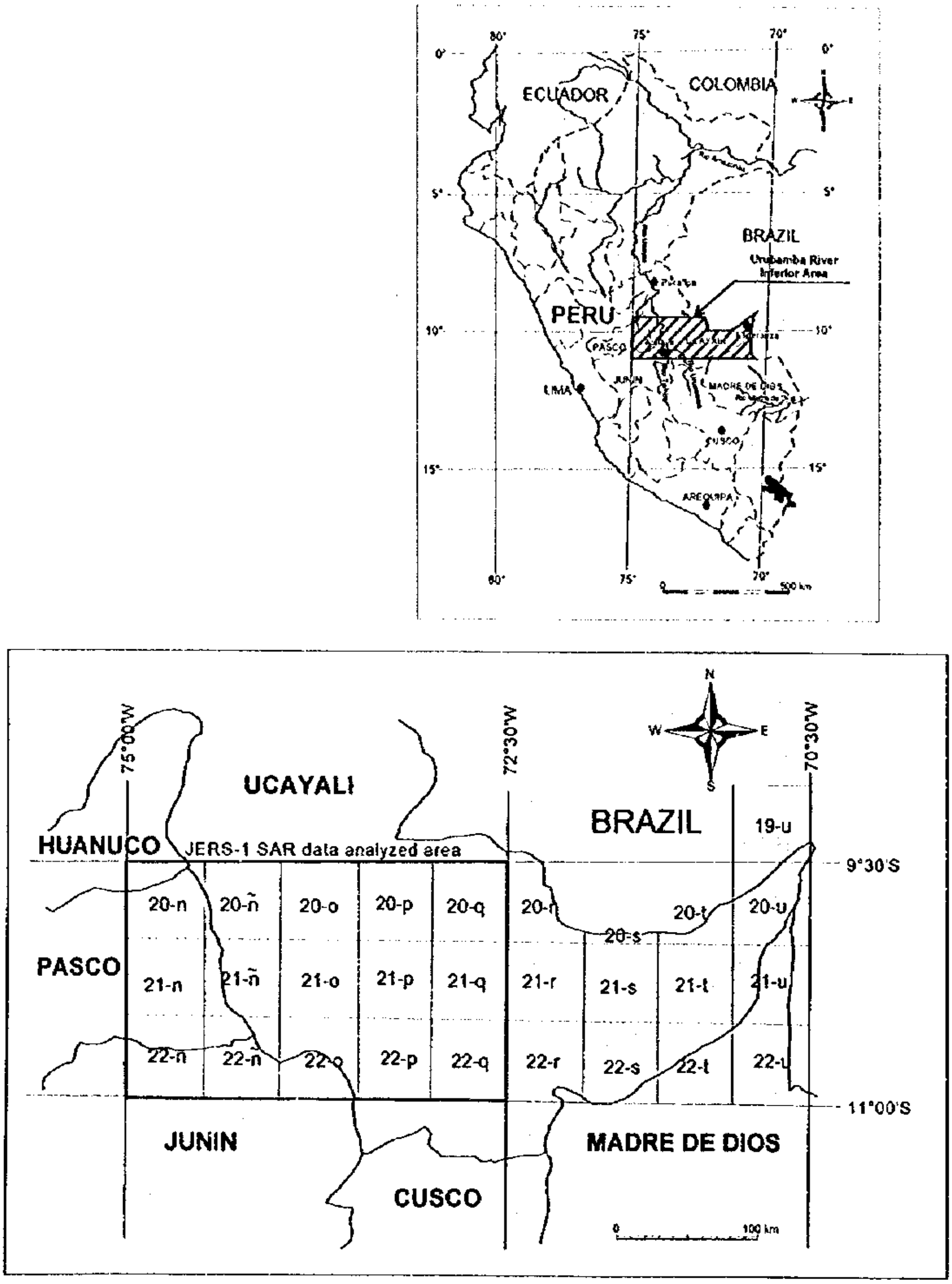


Figure 1 Location of the survey area

PART I

GENERALITIES

Chapter 1 Outline of the Survey

1-1 Antecedents and Purposes of the Survey

Peru ranks among the nations most richly endowed with underground resources. The land covers an area of 1,285,220 km^2 and its zonal distribution of the topography, geologic provinces and metallogenic provinces are nearly parallel from the Pacific coast eastward.

The metallogenic provinces in Peru consist of 1) the iron belt in the southern coastal range, 2) the copper belt in the Pacific coastal piedmont, 3) the polymetallic belt in the highlands (Sierra), 4) the polymetallic belt in the east Andes, and the zone called Selva spreading farther east of 4) in the Amazon upstream basin whose metallogenic zoning has not been fully clarified as yet. Large-scale and low-grade dissemination type gold ore deposits in massive silicified rocks have been discovered and noticed in the polymetallic belt in the northern highlands recently.

In compliance with the request of the government of Peru, the survey was conducted with an aim to effectively select promising zones from the extensive area in a short period of time, by means of satellite image analysis, existing data analysis and integrated studies of survey findings of an area upstream of the Amazon in eastern Peru, which covers the Ucayali River Basin and its upper tributaries, the Urubamba and the Tambo, where the metallogenic zoning has not been clarified in detail.

Simultaneously, it is intended to promote technology transfer to the INGEMMET - Instituto Geológico Minero y Metalúrgico, the Peruvian counterpart, concerning the methods of survey and analysis.

The survey was executed in accordance with the Scope of Work signed by the both governments on November 5, 1998.

1-2 Scope and Outline of the Survey

In the first fiscal year's survey, the satellite image analysis was performed on 15 quadrangles (72°30' - 75° W, 9°30' - 11° S, Figure 1) of the Urubamba river inferior area (about 65,500 km^2), designated in the Scope of Work agreed to between the JICA/MMAJ and the Ministry of Energy and Mines/INGEMMET, that consists of 28 quadrangles of 1:100,000-scale topographic maps, whilst the existing data analysis covered the whole area of the Urubamba river inferior area.

The survey was carried out in the following manner.

The satellite image processing and interpretation were conducted mainly in Japan after obtaining the JERS-1 SAR data and the 1:100,000-scale topographic map (partly in satellite map). The existing data analysis was conducted in Lima and Japan after the geological and mining information were obtained in Peru. During the survey, some parts of the JERS-1 SAR data processing and interpretation were conducted at the INGEMMET's head office in Lima, in collaboration with its engineers, in an effort to transfer of image analysis technic.

As the result of the satellite image analysis and the existing data analysis, the geologic interpretation maps and the lineament maps, as well as the list of ore deposits/mineral indications and the regional potential evaluation map, were elaborated.

1-3 Organization of the Survey Team

The members from the both countries of the prior consultation team and the field survey team are listed in the Tables 1 and 2, respectively.

Table 1 Mission for previous agreement and negotiation

Peruvian side		*Japanese side*	
Ing. Juan Mendoza Marsano	INGEMMET	Mr. Humihiko Kimura	MMAJ
Ing. Hugo Rivera Mantilla	INGEMMET	Mr. Hidefumi Nakashima	MITI
Ing. José León Aparicio	INGEMMET	Mr. Takashi Kamiki	MMAJ
Ing. Oscar Palacios Moncayo	INGEMMET	Mr. Hiroaki Kagawa	MMAJ
Ing. Yorry Elena Carrasco Pinares	INGEMMET	Mr. Tomoo Hayakawa	JICA
Ing. Julio C. Zedano Cornejo	INGEMMET	Mr. Hitoshi Shimoda	MMAJ
Ing. Marco A. Lara Moreno	INGEMMET		

INGEMMET: Instituto Geológico Minero y Metalúrgico
MMMJ: Metal Mining Agency of Japan
MITI: Ministry of International Trade and Industry
JICA: Japan International Cooperation Agency

Table 2 Mission for the field survey

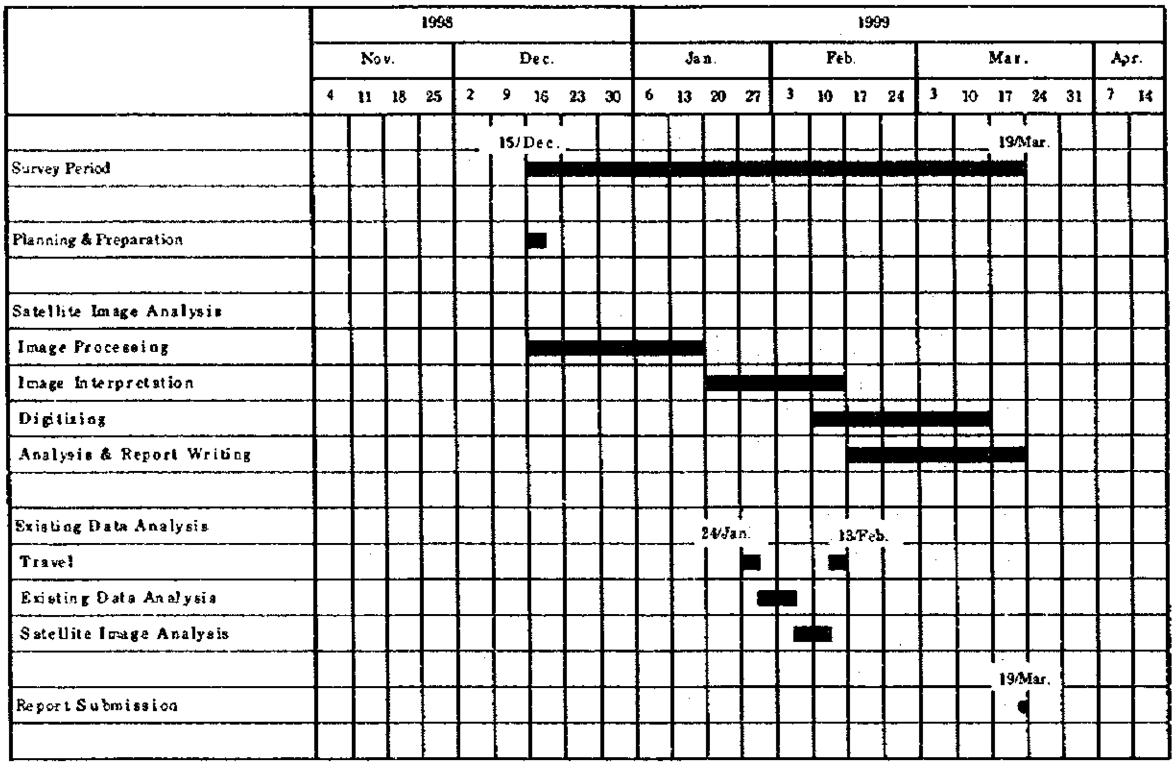
Peruvian side		*Japanese side*	
Ing. Manuel Paz Maidana	INGEMMET	Mr. Kaoru Sakogaichi	MINDECO
Ing. Marco A. Lara Moreno	INGEMMET	Mr. Kazuhiro Adachi	MINDECO
Ing. Washington Larico Cayo	INGEMMET		

INGEMMET: Instituto Geológico Minero y Metalúrgico
MINDECO: Mitsui Mineral Development Engineering Co., Ltd.

1-4 Period and Quantity of the Survey

The survey period is indicated in Table 3.

Table 3 Study period



The quantities of the survey are indicated in Table 4.

Table 4 Quantity of the study

Survey items	*Quantities*
Satellite image analysis Existing data analysis	15 quadrangles (the western potion of survey area) The entire Urubamba river inferior area

Chapter 2 Geography of the Survey Area

2-1 Location and Transportation

The survey area expands 750 km in E-W direction, from 250 km ENE (75°W) of Lima, a capital of Peru, to the Brazilian border (70°30'W) and 170 km in N-S direction from the down stream of Urubamba river towards north, and it covers about 65,500 km^2 (Figure 1).

The main administrative divisions covered by the area are the Departments of Pasco, Ucayali and Madre de Dios, as well as the Cities of Atalaya and Esperanza, the former falling on the south end while the latter on the east end of the area. Atalaya, population 15,200, is the seat of the Atalaya District government and has the police and military stations, hotels and restaurants, etc.

Atalaya is accessible by air from Lima, via Pucallpa. It takes 1:15 hours from Lima to Pucallpa and one hour from there to Atalaya.

The transportation in the survey area is limited to either chartered small planes or small vessels. Major towns and villages have runways in nearby areas for landing of small planes.

2-2 Topography and Drainage System

The western part of the survey area topographically included in the Sub-Andes mountains adjacent east to the Cordillera Oriental of the Andes, and the eastern part included in the Selva, or the lowlands embracing the Amazon's upstream.

The Sira range, altitude 2,000 m, trending NNW-SSE, lies in the survey area at around long. 74°75' W within the Sub-Andes. A stretch from the Ucayali basin to the Brazilian border is the Selva, where flatlands, alt. 200 to 300 m, spreads out; the Ucayali river flows down along the east side of the Sira range in the NNE direction.

The main upper tributaries of the Ucayali river are the Urubamba and the Tambo river, which merge near Atalaya. The Urubamba river has its origin in the Lake Titicaca in southern Peru. By way of Cuzco and the Camisea gas field, it enters the survey area where it changes course from northwest to west to join the Ucayali. Within the survey area, tributaries such as the Inuya (from the right bank) and the Sepa (from the left bank) flow into the Urubamba river.

The northeast side of the line connecting lat. 11°S - long. 72°30' W and lat. 9°30' S - long. 75°30' W in the survey area pertains to the basin of the Purús and the Yurúa, both of which enter Brazil and run into the Amazon. Within the survey area, the Purús runs down northeastward whereas the Yurúa meanders but generally runs northward.

2-3 Climate and Vegetation

Both the Sub-Andes including the Sira range and the Selva have the rainy season roughly from November to April and the dry season from May to October. The climate in the Selva is generally hot and humid, with certain fluctuations of the atmospheric temperature in a day. The average annual temperature and precipitation in Atalaya (1934 - 1935) are 15.7°C and 3,029.5 mm, respectively. The average monthly temperatures and precipitations are tabulated below.

Table 5 Monthly average temperature and precipitation in Atalaya (1934-1935)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Temp. (°C)	26.2	26.4	25.9	25.6	26.1	25.6	24.4	24.3	25.0	25.7	26.4	26.0
Precip. (mm)	294.0	291.4	423.4	364.4	121.2	156.2	100.0	137.4	208.9	211.1	421.1	300.0

The zonal distribution of flora in the survey area is as follows:

a) Tropical jungles (Selva)
   The flora comprises trees parasitized by orchids, vines, etc., and the lichens. As thick forests block off the sunlight, plants in the Selva tend to have leaves of gigantic sizes.
b) Evergreen trees in highlands
   Compared with the Selva, the density of trees is low due to strong wind, forest fires, fall of old trees, etc.
c) Ferns in marshlands
d) Ranges of reeds
   Reeds range along rivers and grow up to 10 m tall.
e) Forest zones on river terraces outside of floodplains
f) Forests of trees and shrubs on fords and playas of large rivers such as the Ucayali.

The greater part of the survey area falls within either the a) or the b) categories.

Chapter 3 Existing Geological Information of the Survey Area

3-1 Outline of Existing Geological Information

In the highlands of the Cordillera Oriental, precious metals, copper, etc. were mined since the Pre-Inca times. During the Colonial period, prospecting, though not systematic, was carried out so vigorously in search of precious metals that gold and silver production increased tremendously. The survey area spreads over the transitional region of the Sub-Andes toward the Selva, which has imposed enormous constraints on transportation and has retarded progress of comprehensive geological studies on the area.

Information on the Selva is very limited due to the transportation difficulties. Geological and mineral surveys were initiated in the 1950's by petroleum companies, which included interpretation of aerial photographs and satellite images and surface geological reconnaissance based on the former. Petróleos del Perú ("Petroperú"), Oficina Nacional de Evaluación de Recursos Naturales ("ONERN," presently Instituto Nacional de Recursos Naturales - "INRENA") have been involved in the survey activities. ONERN's natural resources surveys were carried out along the Urubamba, the Tambo and the Alta Yurna upstream, situated in the central part of the survey area.

As regards surveys of placer deposits undertaken by private firms, the Banco Minero del Perú is engaged in the systematic assessment in accordance with the Presidential Decree D.S. No. 010-74-EM/DGM, which is purported to protect small miners and also to ensure effective utilization of natural resources. Occurrence of placer gold deposits in the survey area is not clearly defined.

As for geologic maps of the survey area, INGEMMET has elaborated 1:100,000 and 1: 200,000-scale maps, while a geologic map at 1: 2,000,000-scale was also compiled by the same Institute in 1995.

3-2 Outline of Geology

According to the geologic map of Peru(INGEMMET, 1995, Figure 2), the highlands in the survey area is underlain by Precambrian metamorphic rocks as the basement; sedimentary rocks of the Oldovician Contaya Formation and of the Carboniferous to early Permian Ambo, Tarma and Copacabana Formations; sandstone of Permian to Triassic Ene Formation; limestone of the Triassic Pucara Formation; sandstone of the late Jurassic Sarayaquillo Formation; sandstone of the Oriente Group; marl and limestone of the Chonta Formation, sandstone of the Vivian Formation and shale of the Cachiyaku-Huchpayacu Formation of the Cretaceous age; and, sanstone-shale-slate of the Paleogene Huayabamba Group. The intrusive rocks are granites presumably of Permian

age and monzodiorite correlated with the Paleogene age.
The Selva zone, stretching from the Ucayali-Urubamba basin to the Brazilian border, is underlain by sandstone-conglomerate of the Neogene Ipururo Formation, gravel of the Ucayali Formation and the Madre de Dios Formation of Pleistocene age, and the Alluvium.

3-3 Outline of Known Ore Deposits

According to the metallogenic studies of Peru, the Cordillera Oriental belongs to the East Andes metallogenic province underlain by the Paleozoic to Cenozoic units, where occurrence of gold-silver bearing copper, lead and zinc ore deposits and prospects, as well as mineral indications of rare metals such as tin, tungsten, nickel and cobalt, has been known. In the highlands of the survey area, which is contiguous with the East Andes metallogenic province, however, only some placer gold deposits are known. Small-scale placer gold mining is still ongoing in the Negro river, a tributary of the Pachitea river at the western piedmont of the Sira range in the west of the survey area.

In the Selva region, whose geologic-metallogenic provinces are not yet clearly defined, Tertiary to Quaternary sedimentary rocks are widespread on the west margin of the Brazilian shield. Ore deposits in the Selva are petroleum, gas and placer gold deposits. Petroleum and gas deposits were investigated by Petroperu and oil companies from 1950's to 70's but the activities have since declined. In March, 1983, the Camisea gas field was discovered 50 km south of the survey area by oil companies including Shell. Small mining of placer gold deposits in Tertiary-Quaternary stream sediments are said to be conducted in the Ucayali and Urubamba river in the central part of the survey area.

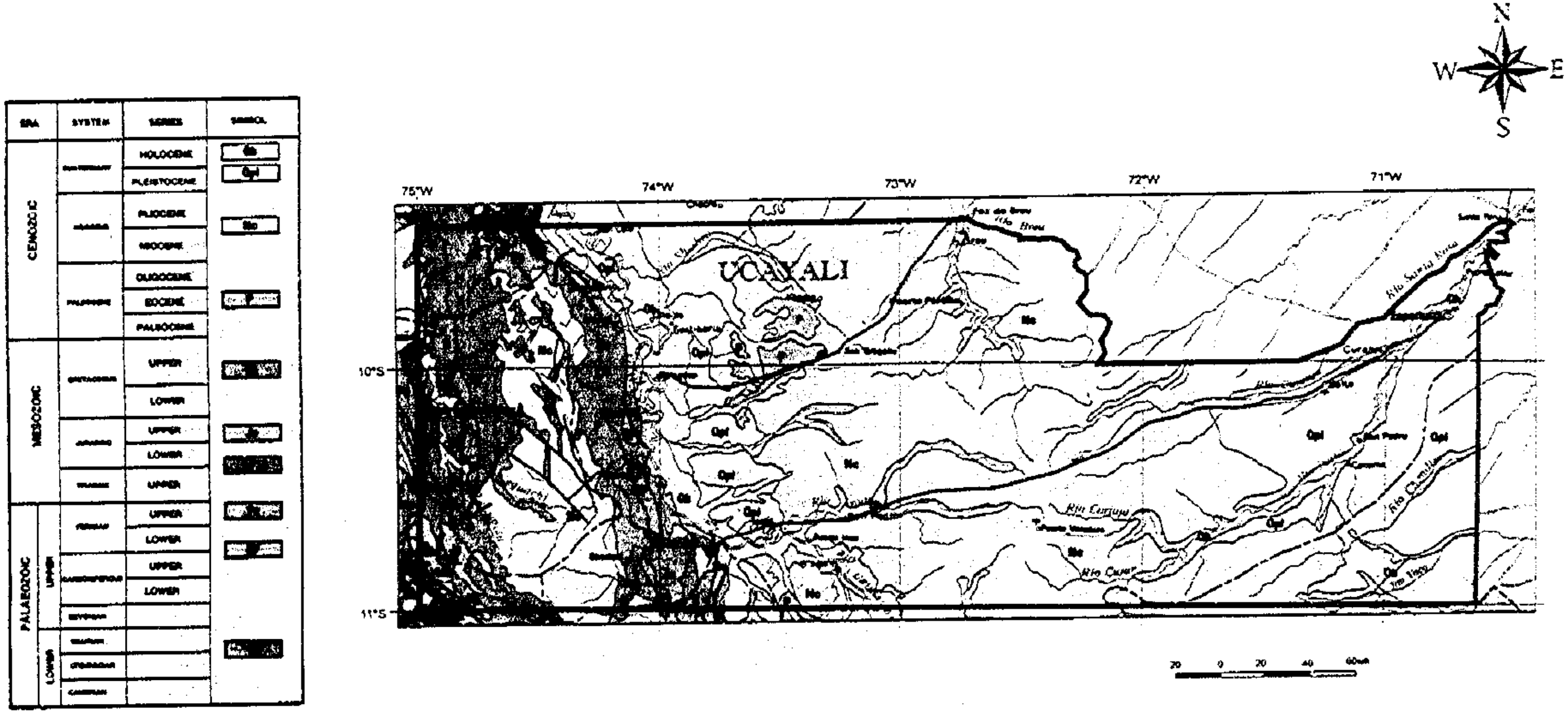


Figure 2 Geology of the survey area

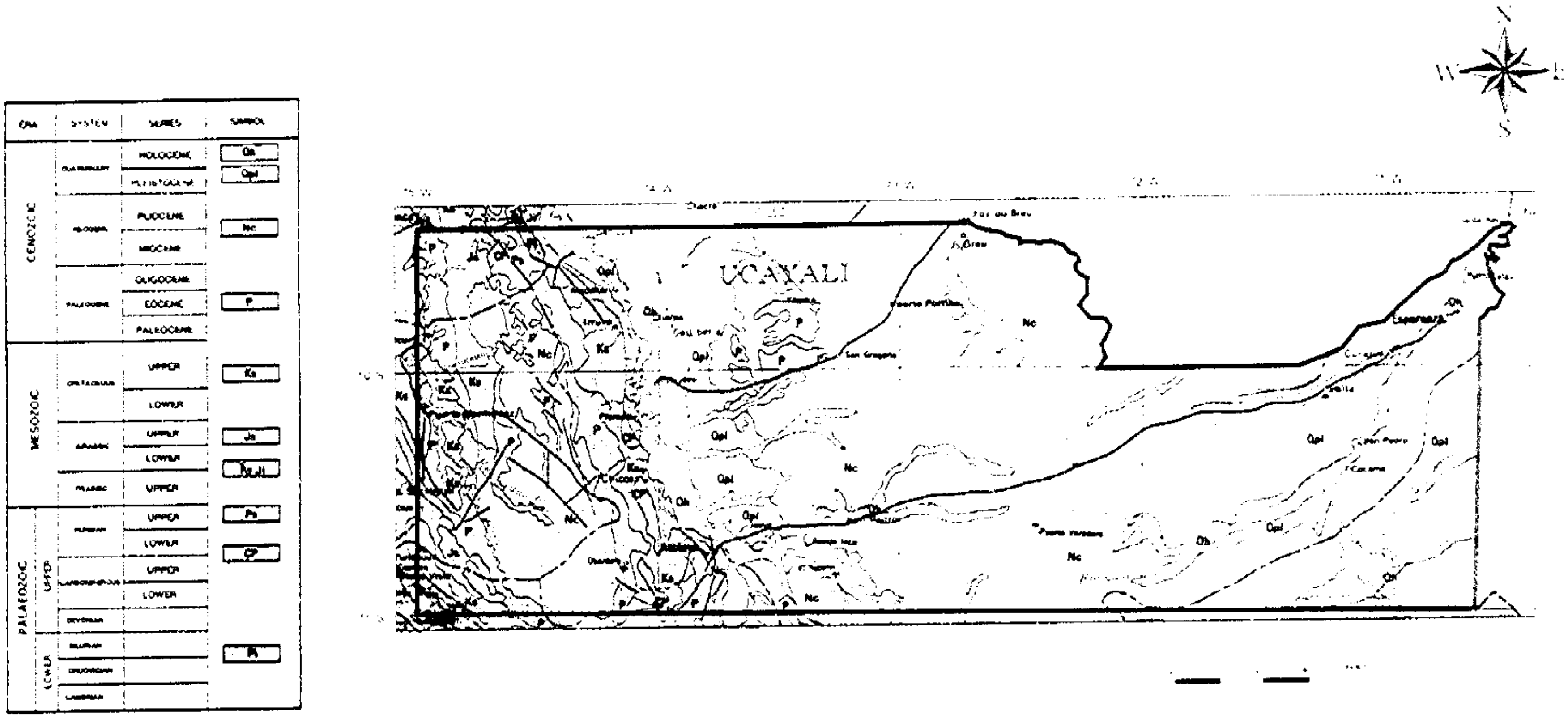


Figure 2 Geology of the survey area

PART II

PARTICULARS

Chapter 1 Satellite Image Analysis

1-1 Purpose of the Image Analysis

The image analysis is intended to produce geologic interpretation maps and lineament maps of JERS-1 SAR images, to examine the regional geologic structure of the survey area, thereby providing basic data for the evaluation of mineral resource potentials in the survey area. The geologic interpretation map elaborated in Phase I covers the 15 quadrangles, 20 to 22 - n, ñ, o, p and q -- a quadrangle represents a square with a side equivalent to 30' of the latitude and longitude -- of the 1:100,000-scale topographic map of the Instituto Geográfico Nacional (IGN).

1-2 Image processing

1-2-1 Data used

Data used for the analysis are 24 scenes of JERS-1 SAR data as indicated in Figure 3 and Table 6.

1-2-2 Procedures for image processing

15 quadrangles of image for interpretation have been processed in the following procedure.

1) Loading data: All the JERS-1 SAR data provided by ERSDAC with EXABITE tapes are copied to the hard disk (HD) connected to an engineering work station (EWS).

2) Separation of header information and image data: From transferred data files, the header files including positioning information of images are extracted and saved in text format. Image data files are converted to the standard image database format of PCI/EASI-PACE, an image processing software developed by PCI of Canada.

3) Bit number conversion: 16-bit image data is converted into 8-bit image data.

4) Histogram normalization: Simultaneously with bit conversion, histograms of digital numbers are normalized.

5) Image rotation: Images are rotated clockwise by 90 degrees.

6) Antenna pattern correction: In order to re-correct the characteristics of antenna pattern of JERS-1 SAR data that an average DN gradually decreases from far range to near range, averages in the azimuth direction of each scene

are calculated , and each pixel value is divided by the average.

7) Coordinates assignment: UTM coordinates of the four corners of each scene are read from header information and assigned.

8) Preparing image database for mosaicking: PCI image database file that has UTM coordinate system for making mosaic image is prepared.

9) Pasting of a center image: Scene P436/R318 near the center of mosaicking area is pasted to the database file for making mosaic images. The pasting position is determined by the information in header file.

10) Mosaicking: Mosaicking is starting from images adjoining the center image. Several dozens of tie-points are collected in an overlapping of images and geometric correction is applied so that the residual error may be reduced to less than 1 pixel. Simultaneously, the brightness is adjusted so that difference in DN value between two images is reduced.

11) Speckle noise reduction: The Enhanced Lee filter (7 x 7) is employed to reduce speckle noises.

12) Extraction of sub-scene images: From the prepared mosaic image, 15 sub-scene images are made so as to correspond to the quadrangles of the 1:100,000-scale topographic map. Geometric correction is again applied so that the sub-scene images may exactly be overlaid on the topographic map, for which confluences and bending points of rivers, etc. are utilized as ground control points for georefferancing.

13) Annotation: Each sub-scene image is annotated with the UTM coordinates, scale bars and titles.

14) File format conversion: The format of image files is converted from PCI database format to TIFF format, so as to fit to the output device used.

15) Alteration of image resolution: Resolution of each sub-scene image is adjusted so as to output at 300 dpi and at a 1:100,000-scale. As the result, the spatial resolution of images was altered to about 8.45 m per pixel.

16) Hard copy output: Two sets of the 15 sub-scene images, totaling 30 images, were output at a 1 :100,000-scale by digital photo-printer (Lightjet 5000). One set was used for the analysis in Japan while the other was used in Peru.

1-3 Image Interpretation, Preparation of GIS Data Set and Lineament Analysis

The output images at a scale of 1:100,000 of the respective quadrangles prepared in the above mentioned procedures were used for image interpretation, and the obtained results were digitized and output at a 1:100,000-scale. The digitized lineament map was used as the input data for computation of the lineament density, whereby the lineament densities of the entire survey area was mapped.

The work was done in the following procedures:

1) Geologic interpretation: Geologic units were classified using surface texture and topographic features on images as criteria. Correlation between the photo-geologic characteristics of each geologic unit and the existing geologic map was tabulated, using the geologic map of the INGEMMET (1995) as reference.

2) Interpretation of lineament and geologic structure: Elements of geologic structure such as faults, lineaments and folding structures were delineated, for which micro-topography was considered.

3) Digitizing: Scanned data of hand-written geologic interpretation maps and lineament maps was loaded on a computer as raster data, which, in turn, was converted to vector data. Figures such as polygons and lines included in the vector data were manually retouched on monitor screen and attributes such as names of structures were added to respective figures. For the series of processing, the TNT Mips, a GIS software developed by Micro Image Inc., USA was employed.

4) Preparation of GIS data set: Geographic data such as drainage systems, lakes, roads, villages and national borders in the MOSS (Map Overlay and Statistical System) format -- one of the GIS standard format by USGS -- provided by INGEMMET was loaded to TNT Mips database file and overlaid on the interpretation results, then annotated with legends, scale, quadrangle numbers, names, etc. and, in turn, output by a color plotter at 1:100,000-scale. The output maps were two types: a geologic interpretation map and a lineament map. From the respective vector data of geologic boundaries, faults, geologic structures and lineaments included in the database files of TNT Mips, the files in the "Export" format (E00 format) of Arc/Info were prepared as the final products.

5) Lineament density map: Lineament data prepared of each quadrangle were integrated into a MOSS-format file, and lineament densities (m/km^2) of 2 km x 2 km grids were calculated by obtaining a cumulative extension of all faults and lineaments included in each grids. For the computation, an analysis tool developed by MINDECO was employed. The lineament density distribution in the entire area of analysis was output at a 1:1,000,000-scale and rose diagrams of each quadrangle were simultaneously produced.

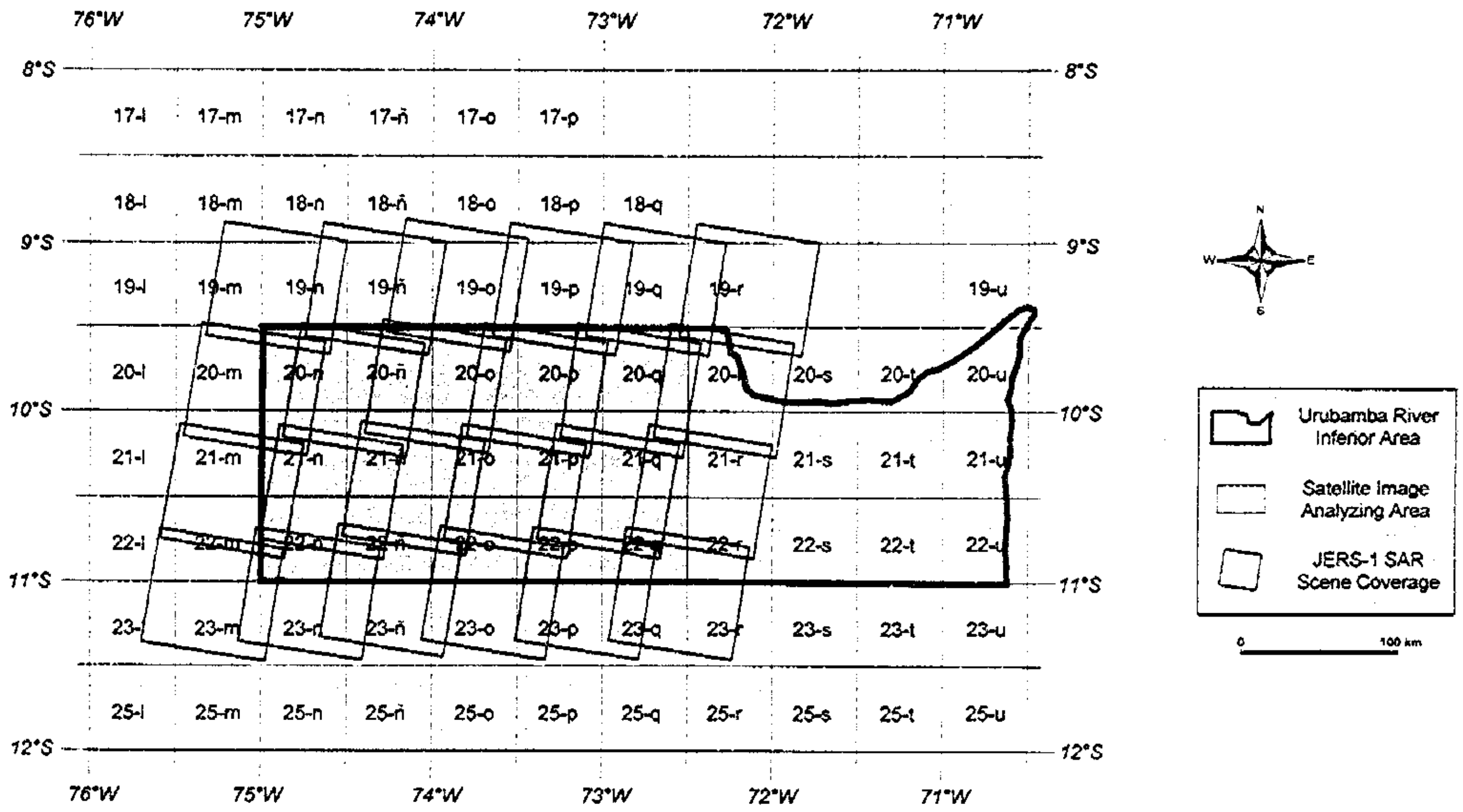


Figure 3 Coverage of satellite data used

Table 6 Satellite data used

	date	sat.	sensor	path	row	lati.	long.	qual.	station
1	1996/06/15	J1	SAR	434	316	-09.17	-72.08	G	HEOC
2	1996/06/15	J1	SAR	434	317	-09.52	-72.17	G	HEOC
3	1996/06/15	J1	SAR	434	318	-10.28	-72.25	G	HEOC
4	1996/06/15	J1	SAR	434	319	-11.04	-72.33	G	HEOC
5	1996/06/16	J1	SAR	435	316	-09.17	-72.41	G	HEOC
6	1996/06/16	J1	SAR	435	317	-09.52	-72.50	G	HEOC
7	1996/06/16	J1	SAR	435	318	-10.28	-72.58	G	HEOC
8	1996/06/16	J1	SAR	435	319	-11.04	-73.06	G	HEOC
9	1996/06/17	J1	SAR	436	316	-09.17	-73.14	G	FAIS
10	1996/06/17	J1	SAR	436	317	-09.52	-73.23	G	FAIS
11	1996/06/17	J1	SAR	436	318	-10.28	-73.31	G	FAIS
12	1996/06/17	J1	SAR	436	319	-11.04	-73.39	G	FAIS
13	1993/03/18	J1	SAR	437	316	-09.17	-73.49	G	FAIS
14	1993/03/18	J1	SAR	437	317	-09.53	-73.49	G	FAIS
15	1993/03/18	J1	SAR	437	318	-10.28	-74.05	G	FAIS
16	1993/03/18	J1	SAR	437	319	-11.04	-74.12	G	FAIS
17	1996/06/19	J1	SAR	438	316	-09.15	-74.19	G	HEOC
18	1996/06/19	J1	SAR	438	317	-09.51	-74.27	G	HEOC
19	1996/06/19	J1	SAR	438	318	-10.27	-74.35	G	HEOC
20	1996/06/19	J1	SAR	438	319	-11.04	-74.43	G	HEOC
21	1994/08/30	J1	SAR	439	316	-09.16	-74.54	G	FAIS
22	1994/08/30	J1	SAR	439	317	-09.52	-75.02	G	FAIS
23	1994/08/30	J1	SAR	439	318	-10.28	-75.10	G	FAIS
24	1994/08/30	J1	SAR	439	319	-11.04	-75.18	G	FAIS

J1: JERS-1, SAR: synthetic aperture radar, G: good, HEOC: Hatoyama, FAIS: Fairbanks

1-4 Results of the Image Analysis

1-4-1 Geologic Interpretation

For interpretation of the images, the existing 1:2,000,000-scale geologic map (INGEMMET, 1995) was used as reference. For geologic interpretation, the geologic map was referred to, while new information obtained through the image interpretation was considered as much as possible. For symbols of geologic units, the geologic ages in the map were referred to, and serial numbers were assigned, in ascending order, to the units sub-divided by the interpretation. SAR image of the entire analyzed area is shown in Figure 4, its geologic interpretation in Figure 5 and lineament map with rose-diagrams of each quadrangle in Figure 6. Table 7 indicates correlation between geologic units of the interpretation map and those of the existing geologic maps.

Characteristic of the respective geologic unit are summarized in the following paragraphs:

(1) Unit Q4
The unit develops along main streams. Countless meandering tracks of old channels are seen. The surface texture of the unit looks smooth and flat. Tones ranging from very light to very dark (in the old channels) are mingled. (Alluvium)

(2) Unit Q3
The unit develops along main streams, forming lower terrace surfaces. Though flat, the surface plane appears to be of rough (sandy) texture. The tone is somewhat dark. (Quaternary terrace deposit)

(3) Unit Q2
The unit forms middle terrace surfaces. Sand grain-like or patch-like, light speckles are seen while the tone is somewhat light. The surface texture looks coarse. (Quaternary terrace deposit)

(4) Unit Q1
The unit forms higher terrace surfaces. It has light and somewhat large-sized patchwork pattern, while the surface texture looks somewhat coarse. (Quaternary terrace deposit)

(5) Unit T4
The area of occurrence is very limited. The unit is a thin bed covering the flat parts of the Unit T2. Although it has rather smooth surface texture, patchwork-like or pinnate drainage pattern is slightly seen. (Upper Tertiary)

Table 7 List of geologic units

No.	Units	Units in Geologic Maps after INGEMMET 1:2,000,000 (1995)	Units in Geologic Maps after INGEMMET 1:100,000 (1997-1998)	Inferred Lithology and Geologic Age
1	Q4	Qh	Qhal	sand, gravel (Quaternary)
2	Q3		NQ-u	lower terrace deposit (Quaternary)
3	Q2	Qpl		middle terrace deposit (Quaternary)
4	Q1		N-i ~ NQ-u	higher terrace deposit (Quaternary)
5	T4	Nc		sandstone, conglomerate (Late Tertiary)
6	T3			sandstone, conglomerate (Middle Tertiary)
7	T2			
8	T1	P		sandstone, conglomerate (Early Tertiary)
9	K4	Ks	Ksh, Ksv, Ks-ch	sedimentary rocks (Late Cretaceous)
10	K3		Ki-o	sedimentary rocks (Middle Cretaceous)
11	K2		Pi-c	
12	K1			sedimentary rocks (Late Jurassic to Early Cretaceous)
13	J	Js	Js-s, TrJi-pu, PsTR-e	sedimentary rocks (Jurassic)
14	P	Pi-c	Pe-cm	sedimentary rocks (Permian)

(6) Unit T3

The Tertiary unit is seen overlying the Unit T2 in the east part of the interpretation area. The unit resembles the Unit T2 but has deeper valleys, characterized by the parallel drainage pattern presumed to reflect the strike of

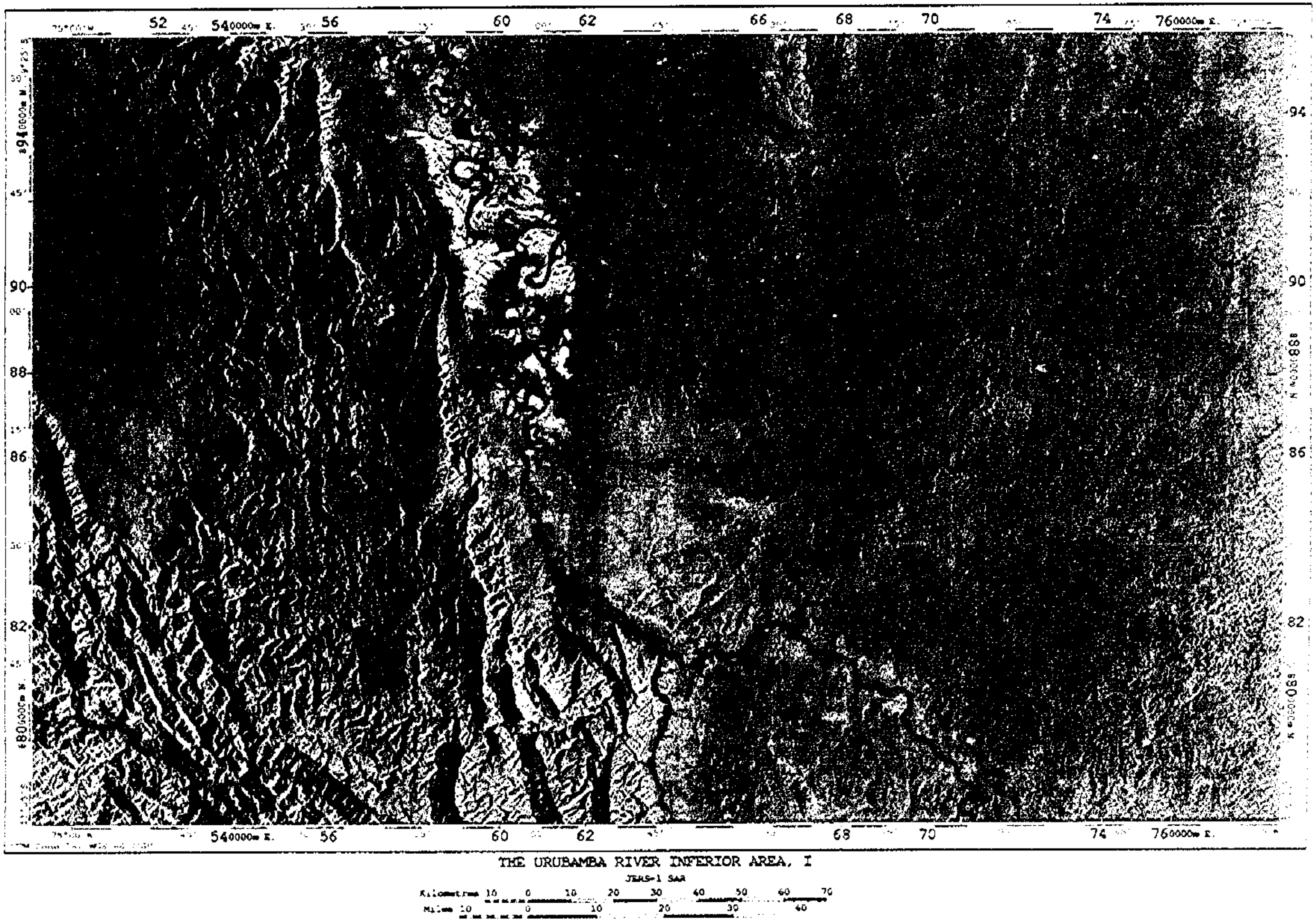


Figure 4 JERS-1 SAR mosaic image

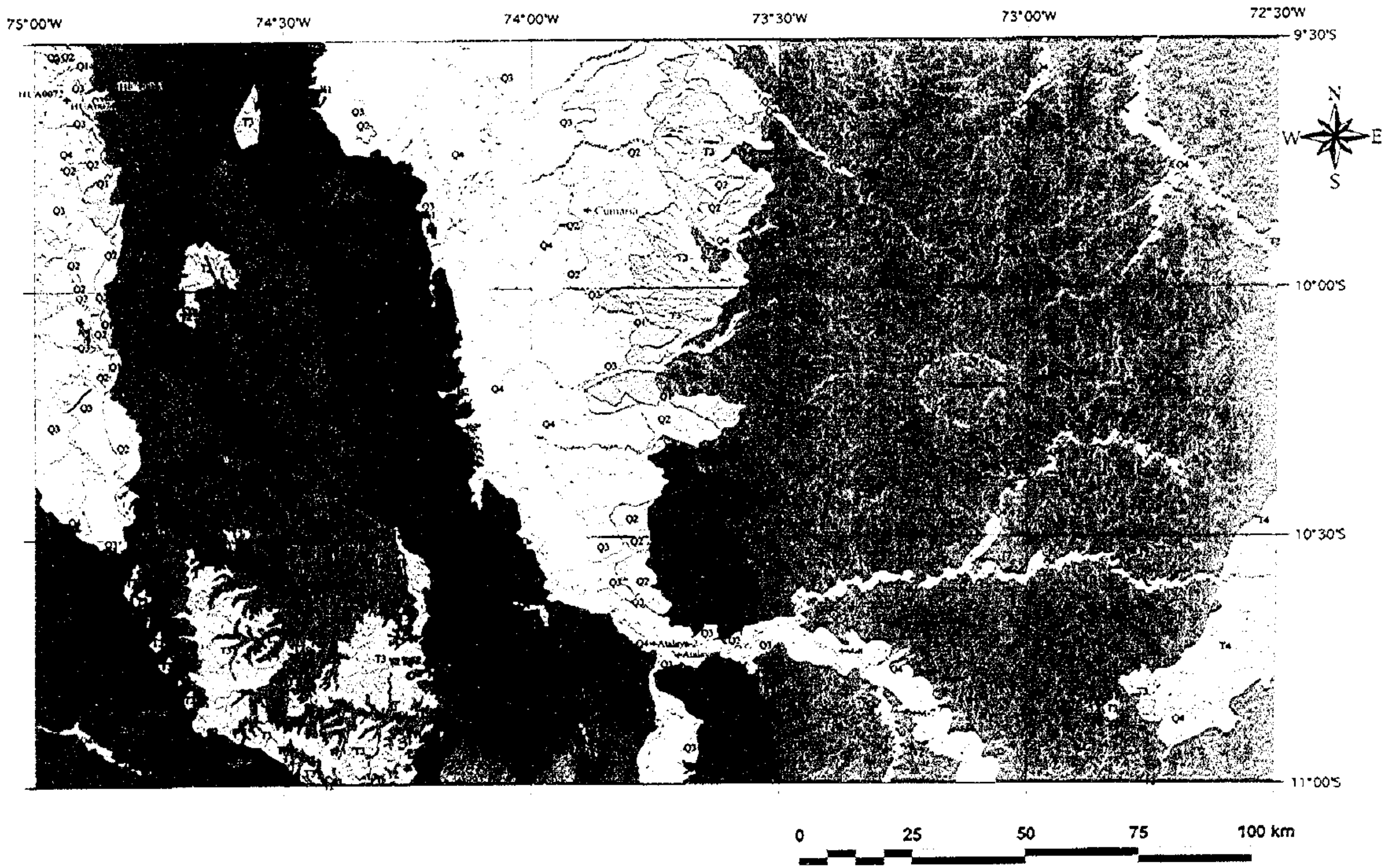


Figure 5-1 JERS-1 SAR geologic interpretation map

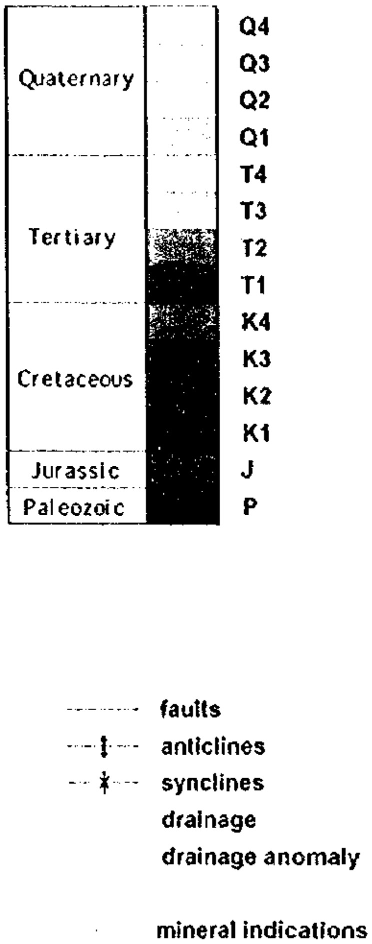


Figure 5-2 Legend of geologic interpretation map

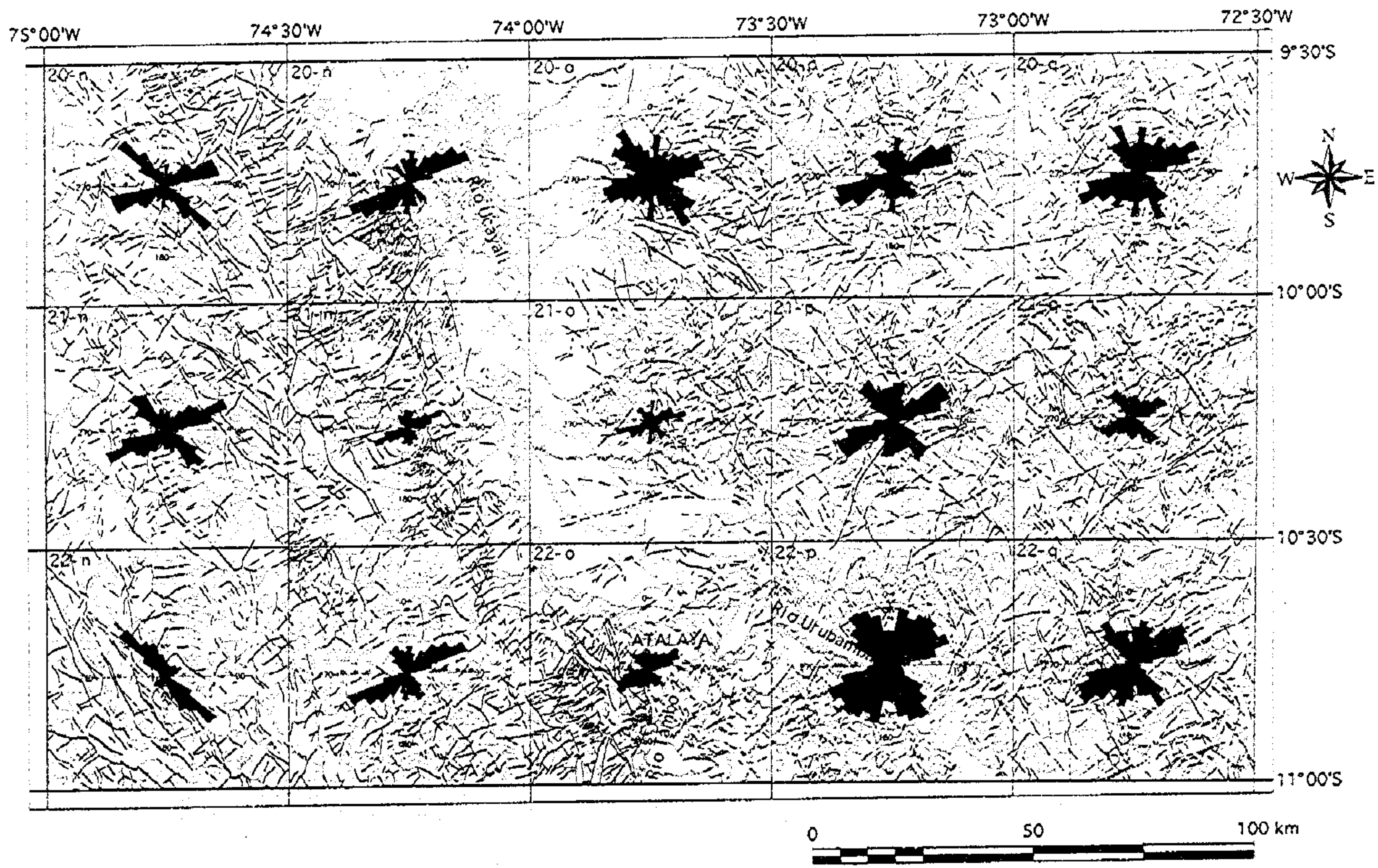


Figure 6 JERS-1 SAR lineament map

the bed. The tone is light on the east side of the slopes and dark on the west side. (Middle Tertiary)

(7) Unit T2
Tertiary unit is predominant especially in the east part of the interpretation area. On flat portions, it has fine, dendritic drainage pattern. The tone is somewhat light. In images, bedding planes are partially traceable but generally unclear, probably because the unit is composed of alternation of thin beds. It is inferred that the unit is chiefly composed of fine-grained, pelitic rocks, intercalating conglomerate beds, sandstone beds, etc. (Lower Tertiary)

(8) Unit T1
The unit, underlain by the Unit T2, is observable at valley portions in areas dominated by the T2. The bed is inferred to be considerably thick. At steep slopes or valleys, fine, parallel drainage patterns develop, and bedding planes in well continuity are occasionally observable but, in general, it appears massive. (Lower Tertiary)

(9) Unit K4
The unit is rarely seen overlying the Unit K2 at flat portions or on gently dipping slopes. The surface texture is smooth but weak undulation develops. As for the tone, light and shade are repeated in a spotted pattern. Bedding is not clear. (Upper Cretaceous)

(10) Unit K3
The unit is often seen forming extensive, moderately dipping slopes while, in some cases, it forms large or small fold structures. As the bedding planes develop and include members which have strong resistance to erosion, steep scarps are frequently formed in the peripheries of the unit. The tone is dark but, at places, there are light patches due to thin covers of the Unit T2, etc. Basically, the drainage shows dendritic patterns but parallel patterns are observed at steep slopes. The unit contacts the Unit J with thrust faults in many portions. (Middle Cretaceous)

(11) Unit K2
The unit is underlain by the Unit K3. These units form fold structures accompanying thrust faults. The K2 has relatively smooth surface texture, though somewhat coarse on gentle slopes. Drainage patterns are not so well developed, and only parallel drainage patterns are observable especially on steep slopes. The tone is somewhat dark but light dots are seen all over. (Middle Cretaceous)

(12) Unit K1
The unit is dominated by joints and the surface texture is coarse. The tone ranges widely from light to dark. Bedding planes are recognizable but not so clearly. (Lower Cretaceous to Upper Jurassic)

(13) Unit J

The surface texture is rough and banding with light and dark tonal portion is observed. Bedding and joint are generally well developed and dipping northeast. NNW-SSE to NW-SE trending large range is developed in the portion showing clear bedding planes. ENE-WSW to NE-SW trending joints are dominant, that is perpendicular to bedding. NNE-SSW trending large-scale thrust is seems to be developed at the boundary between this unit and Cretaceous. Massive portions without clear bedding plane are partly observed and where dominant range direction does not appear. (Jurassic)

(14) Unit P

Fissures parallel to bedding planes or joint planes are well developed and surface texture is generally coarse. The tone is light, except the dark slope in the west. Bedding planes are occasionally visible but they are generally unclear. The unit is often seen as inliers in K2 or K1, presumably accompanied with thrust faults. The unit is inferred to be mainly composed from hard rocks such as sandstones or limestones. (Peleozoic)

Some examples of geologic interpretation maps are exhibited in Figures 7-2 (quadrangle 20-n), 8-2 (21-ñ), 9-2 (22-o) and 10-2 (22-p), and those of lineament maps are in Figures 7-3 (20-n), 8-3 (21-ñ), 9-3 (22-o) and 10-3 (22-p).

The interpretation of the respective quadrangles is summarized below.

(1) 20-n

The extreme west of the quadrangle corresponds to upper stream of the Pachitea river, where an extensive basin composed of Alluvium and terrace deposit is formed. In the central part of the quadrangle, Cretaceous extends south to north, gently dipping westward, while the east part is underlain by Tertiary. In the extreme east of the quadrangle, Cretaceous bedding plane is clear, stretching south to north and dipping west, whilst Tertiary appears to the east. From this, it can be inferred that these are bounded by thrust faults.

(2) 20-ñ

On the east side of the quadrangle, an extensive basin is seen in the Urubamba river inferior area. Around Alluvium, embracing countless tracks of meandering old channels, terrace deposits spread on the surface. The Sira range composed from Paleozoic to Tertiary units lies in the west. A fault supposed to be a thrust is running in N-S direction and changes its direction to NW-SE in the south. Anticlines formed in the east of the fault have N-S to NNW-SSE trending axes parallel to the strike of thrust fault.

(3) 20-o

Quaternary overlies most of the area. On the extreme west of the quadrangle, an extensive alluvial basin develops along the Ucayali river, in the east of which, low and middle terrace spread out. On the extreme east of the quadrangle, Tertiary Units T2 and T3 are seen. Faults and folding structures are unclear.

(4) 20-p
Most of the area is covered by Tertiary Unit T2. Undulation is generally weak and valleys are relatively shallow. In the east, NNW-SSE to N-S trend bedding planes with eastward dips are continually observed. The radial drainage pattern observed in the northern-central portion of the quadrangle suggests the existence of NNW-SSE trending syncline or dome structure. While the basic drainage pattern is dendritic, parallel patterns and fine pinnate patterns also develop, which are presumably controlled by bedding.

(5) 20-q
Like the 20-p, Tertiary Unit T2 prevails all over. Undulation is moderate, and valleys are relatively shallow. Along the Alto Yurua river which runs from south to north in the central part of the quadrangle, fluvial sediments of Q3 are seen. The radial drainage pattern in the Northeast of the quadrangle presumably indicates the existence of anticline elongated in N-S direction. The drainage patterns are basically dendritic but parallel patterns and fine pinnate patterns also develop, which are presumably controlled by bedding.

(6) 21-n
The western area of the quadrangle covers upper stream basin of the Pachitea river and an extensive flat plane is formed. Narrow Cretaceous unit crops out in the Center with N-S trend but, in the east of there, it is completely covered by Tertiary. Cretaceous is gently dipping westward, whereas Tertiary is almost flat.

(7) 21-ñ
The east side of the quadrangle corresponds to the upper stream of the Ucayali river, where an extensive alluvial basin is formed. To the west of Quaternary, Cretaceous, partially including Jurassic, is widespread. Cretaceous forms anticlinorium with the axes in N-S trend in its east periphery where it accompanied by thrust fault, whereas, in the west side of the thrust, it forms a gentle monoclinal structure. The west side in the quadrangle is completely covered with Tertiary. Tertiary has nearly horizontal structure and is cut by large faults with N-S or NW-SE trend.

(8) 21-o
On the extreme west of the quadrangle, the alluvial basin (Q4) on the right bank of the Ucayali river continues south to north. On the east side of the basin, an extensive terrace surfaces consisting of Q3 (lower terrace surface), Q2 (middle terrace surface) and Q1 (higher terrace surface) spread out. Dendritic drainage pattern develops in Q1, while the other terrace surfaces are flat and have low drainage density. The extreme right portion of the quadrangle is underlain by T2. The drainage patterns are mainly dendritic or fine pinnate patterns, but valleys are not deep. There are many linear features presumably indicating bedding planes, and other lineaments intersecting the bedding

planes also dominant. It is hard to distinguish those lineations and to interpret the details of geologic structure.

(9) 21-p
The entire area is underlain by T2. Undulation is generally small and deep valleys are not observed. The drainage density is very high and the main streams make dendritic patterns whilst the tributaries make fine pinnate patterns. Bedding planes are observable everywhere, which however cannot continuously be traced, because of disturbance by fine drainages. A zone having characteristic trellis drainage pattern is located in the central east of the quadrangle, which possibly suggests the existence of intrusive unit.

(10) 21-q
The T2 covers most of the area. On the whole, undulation is scarce and deep valleys are not developed. The drainage is very dense. The main streams have dendritic patterns while the tributaries have fine pinnate patterns. Bedding planes are observable everywhere, which however cannot continuously be traced, because of disturbance by fine drainage. A dome structure is inferred from the radial drainage pattern in the central east of the quadrangle.

(11) 22-n
On the east side of the quadrangle, a nearly horizontal Tertiary forms "Mesa" and broadly overlies Cretaceous. As seen in the central portion of the quadrangle, Tertiary is cut by faults in NNW-SSE to NW-SE direction and is not present on the west side of the faults. Cretaceous and Jurassic form synclinal structure and cover the southwest of the quadrangle.

(12) 22-ñ
On the east side of the quadrangle, Cretaceous and Jurassic are widespread and accompanied by thrust faults in nearly N-S direction. Cretaceous forms anticlinal structure with the axis parallel to the thrust faults and is gently dipping westward in the west side of the fault. In the east half of the quadrangle, Tertiary is widespread, overlying Cretaceous. Tertiary forms a nearly flat structure, whose continuous bedding planes are clearly observed.

(13) 22-o
Near the central portion of the quadrangle, the Urubamba river from the east and the Tambo river from the south merge into the Ucayali river, which flows down northwestward. Along these rivers, an extensive basin, covered by Q4, is formed. Outside of the basin, lower terrace (Q3), middle terrace (Q2) and higher terrace (Q1) are observed. Of these, the higher terrace is markedly superior to the others in respect of the height. While there remain surfaces where drainage systems are undeveloped, erosion has proceeded in valleys. On the east side of the Tambo river, T2 is widespread. Large, meandering rivers are seen but, on the whole, fairly fine drainage systems are assembled. Countless linear patterns are observed but they are traversed by other linear patterns, or directions of their dips are unclear due to weak undulation; the structure is hard to clarify.

The Sira range mainly composed of K1, K2 and K3 rises on the west side of the Tambo and Ucayali river. A number of faults trending NNW accompanied by oblique faults are seen. Valleys along the faults are deep and steep. At least two thrusts with NNW-SSE to N-S trend are developed near the boundary between Sira range and Ucayali basin and tree anticlines divided by these thrusts are formed.

(14) 22-p
Fluvial sediments of Q2 are widespread along the Urubamba river, the Inaga river, the northern tributary of that, and the Sepa river, the southern tributary of the same, which flow in the central portion of the quadrangle. The surrounding areas of these rivers are fully covered by the Tertiary unit T2, where the undulation is weak and valleys are shallow, in general. Near the extreme east of the quadrangle, linear patterns seemed to be bedding planes are hardly observed, which, occasionally bending, stretches almost in parallel with each other in the N-S direction and generally dipping southeast. In a little north of the center of the quadrangle (centering around the area between the Urubamba and Inuya river), a semi-circular bedding planes are seen if not clearly. Since a radial drainage pattern is also observed there, a dome structure possibly formed.

(15) 22-q
Almost all the area is covered with Tertiary (T2 and T3). Similar to the 21-q, the area has little undulation in general and no deep valleys are observed, but valleys in T3 are little deeper than that in T2. The drainage systems are very dense, composed of the main streams with dendritic patterns and the tributaries with fine pinnate patterns. Bedding planes(?) dipping gently southeast are hardly observable in the northwest to southwest portion of the quadrangle, where T3 mainly underlies the surface. The drainage pattern in the same portion is clearly controlled in NE-SW direction and shows rectangular pattern. This direction certainly represents strike of bedding.

1-4-2 Lineament analysis

The results of lineament analysis of the respective quadrangles are summarized below:

(1) 20-n
In the areas covered by the Quaternary and the Unit K2, lineament density is very low. On the whole, lineaments with NW-SE, NNW-SSE and ENE-WSW trends are predominant.

(2) 20-ñ
The lineaments in the areas covered by the Quaternary include innumerable parallel lines presumed to reflect the strikes of the underlying beds. These lineaments are unclear and the direction of dips are uncertain. Lineament density is high in the west area, especially where the Cretaceous is present.

Lineaments with N-S and ENE-ESW trends are predominant.

(3) 20-o
In the western area covered by the Alluvium, there is no lineament worthy of mention, except the numerous meandering tracks of old river channels. In the area covered by T2 and T3, lineaments with NW trend are dominant and are good in continuity, which are followed by those with ENE and EW trends.

(4) 20-p
The lineament density is high. Lineaments with NNW and ENE trends predominate. Many bedding planes are observable, but the structure is hard to ascertain since they are intersected with numerous lineaments.

(5) 20-q
Similar to the 20-p, the quadrangle has high lineament density, and lineaments with NNW and ENE trends are predominant. In the area covered by Q3, innumerable lineaments with the ENE trend are seen.

(6) 21-n
Lineaments with NW-SE and ENE-WSW trends are dominant and good in continuity. In the areas covered by the Tertiary Unit T2, lineament density is low.

(7) 21-ñ
In the area covered by the Quaternary, lineament density is very low. Lineaments with NNW-SSE and ENE-WSW are dominant. Especially near the thrust faults in the east, lineament density tends to increase.

(8) 21-o
Few lineaments are observable in the areas covered by Quaternary, while lineament density is high in the east area covered by T2. Lineaments with ENE and NNW trends are especially dominant.

(9) 21-p
On the whole, lineament density is high. Especially, lineaments with ENE and NW trends are dominant and good in continuity.

(10) 21-q
Similar to the 21-p, lineament density is high, on the whole. Especially, lineaments with ENE and NW trends are dominant and good in continuity.

(11) 22-n
Lineaments with NNW-SSE and NW-SE trends which are parallel to the thrust fault are dominant. In the area covered by Tertiary on the east side of the quadrangle and by Jurassic in the southwest end, lineaments with NE-SW trend are also dominant.

(12) 22-ñ

On the whole, lineaments with ENE-WSW and NWN-SES trends are dominant. In the area covered by Tertiary in the central portion of the quadrangle, lineaments are not so well developed.

(13) 22-o

In the area covered by K2 and K1 on the west side of the quadrangle, lineament density is high, as compared with the east area covered by Quaternary and Tertiary. Above all, deep valleys presumably formed by faults develop and lineaments with NNW and NS trends are dominant along the valleys. Lineaments with NE trend also develop and few of them are good in continuity and large in size. In the Unit T2 on the east side of the quadrangle, lineaments with NNW to NW and ENE trends are good in continuity. Many lineaments presumed to reflect bedding are observed but these are too poor in continuity and untraceable to clarify the structure.

(14) 22-p

On the whole, lineament density is high. Especially, lineaments with ENE and NW trends are dominant and good in continuity.

(15) 22-q

Similar to the 22-p, lineament density is high, in general. Especially, lineaments with NE, NW and NS trends are dominant and good in continuity. As compared to the Unit T2, lineaments in T3 are clearer.

1-5 Considerations

A comparison between the image interpretation and the 1:100,000-scale geologic map published by the INGEMMET in 1997-98 (List of Reference and Data Collected -1) is summarized as follows:

a. The interpretation findings and the existing geologic map are in substantial agreement, in terms of the general division of geologic unit.

b. Due to the lack of ground data for the verification of interpretation findings, the respective geologic time units are hard to identify and, precision-wise, the interpretation results are inferior to the geologic map, in terms of detailed division of the geologic unit.

c. Owing to the distortion peculiar to a radar image, the fault lines and geologic boundary lines in the interpretation map tend to be distorted, especially in mountainous zones with high specific altitude.

d. In the Tertiary zone in the east where bedding planes are observable all over in spite of its flat topography, a verification survey, if conducted, is expected to be able to clarify the large and small folding structures more in detail.

e. The geologic map and the interpretation map do not agree as to the geologic division of Permian in the quadrangles 20-ñ, 20-n, etc. of the geologic map. In the map, the unit underlain by the horizontal to moderately dipping Cretaceous that constitutes the main body of the Sira range and apparently conforming to the overlying stratum is classified into the Permian. Since it is clear from the SAR images that Cretaceous is composed of a number of members (alternation of beds of high and low resistance to erosion), the unit is dealt with in the interpretation map to be the lowest member of Cretaceous.

f. The unit with rough texture and with well developed lineaments, lying in the vicinity of the Sira anticlinal axis in the quadrangles 20-ñ and 20-n, is classified in the geologic map into Proterozoic, whereas the interpretation map classifies it into Paleozoic in conformity to the division of the 1:2,000,000-scale geologic map, since no reference to Proterozoic have so far been found in the Sub-Andes studies and in view of the mentioned relations with Cretaceous.

The western part of the interpretation area on the left bank of the Ucayali-Tambo rivers, where the Sira range is formed, is mainly composed of Paleozoic to Cretaceous, whilst the Ucayali sedimentary basin area in the eastern part, Tertiary to Quaternary are widespread forming relatively moderate landforms. The two areas are clearly divided by the thrust faults in NNW-SSE direction which serve as the boundary. In Paleozoic to Cretaceous in the Sub-Andean region, large to small-scale fold structures with axes parallel to the strike of the thrust faults are formed.

In Tertiary to Quaternary in the Ucayali sedimentary basin area, presence of a number of anticlinal structures or dome structures are inferred from drainage patterns. These structures are likely to reflect concealed Cretaceous or lower depths structures. The anomalous drainage pattern discerned in the quadrangle 21-p -- a distinctive trellis pattern -- appears interesting as it possibly suggests presence of an intrusive rock. In the Selva zone as represented by the Ucayali sedimentary basin area, drainage analysis is effective for interpretation of geology and geologic structure.

Figure 11 demonstrates a lineament density map. In the thrust zone trending NNW-SSE located in the east of the Sira range, many parallel lineaments to the thrusts, considered to reflect small faults accompanying the thrusts, and many intersecting lineaments to the thrust trending ENE-WSW, possibly reflecting tension fractures or strike-slip faults, have been extracted and those lineaments form high density zones of lineament in this zone. In general, tension fractures are possibly accompanied by intrusive rocks and hydrothermal activity related with the intrusive rocks; therefore, they are considered important for exploration.

The presence of small-scale intrusive rock bodies in Paleozoic in the southeast of the Sira range has been confirmed from the field data by INGEMMET, which suggests that similar rock bodies possibly lie in the zone. Although a zone of intrusive rocks cannot be interpreted from SAR images, the most part of the Phase I study area is covered by Jurassic to Quaternary sedimentary rocks or unconsolidated sediments and therefore fissures are presumed not to be well developed. It is also inferable that, in such an area, intrusive rocks and metamorphic rocks are likely to be present in portions of high lineament density.

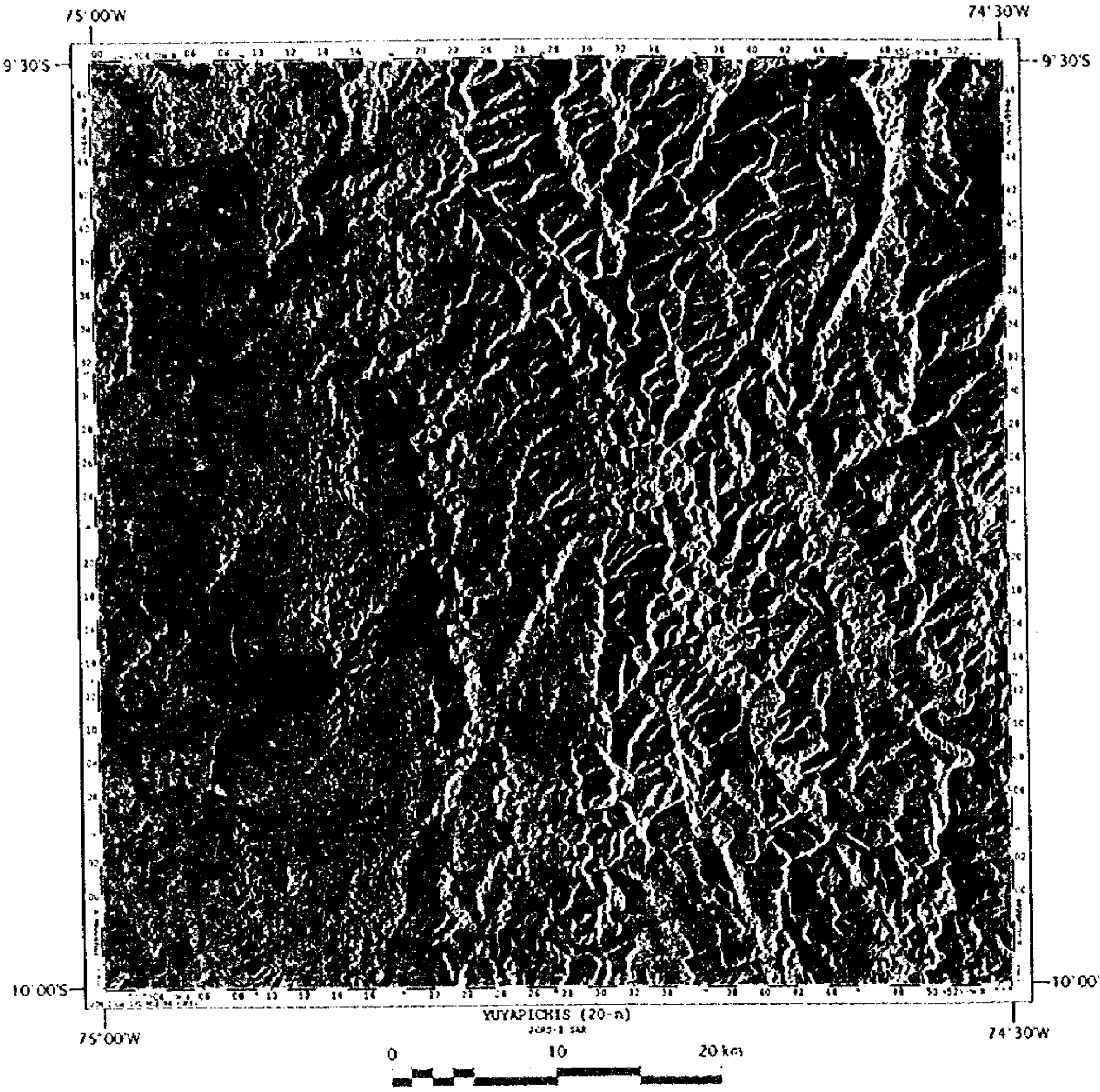
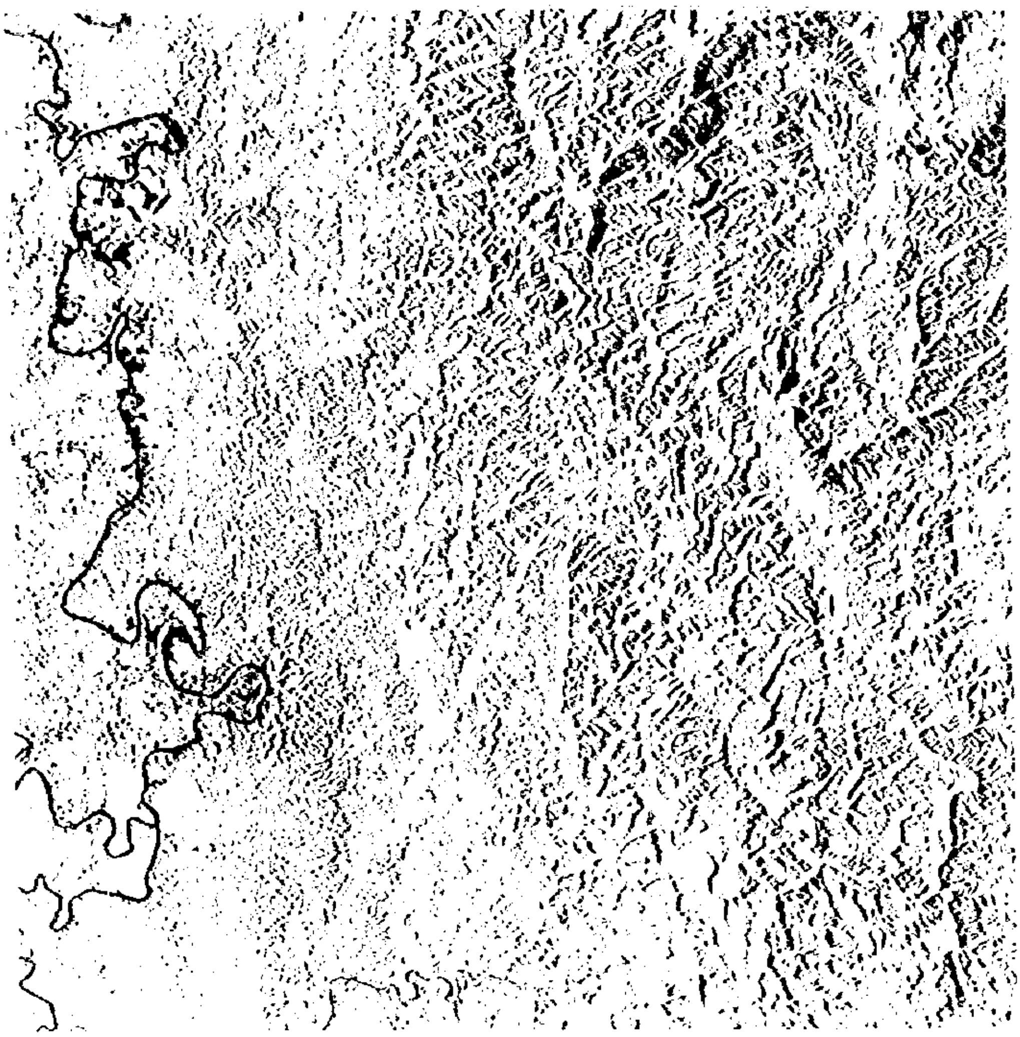


Figure 7-1 Yuyapichis (20-n) JERS-1 SAR image



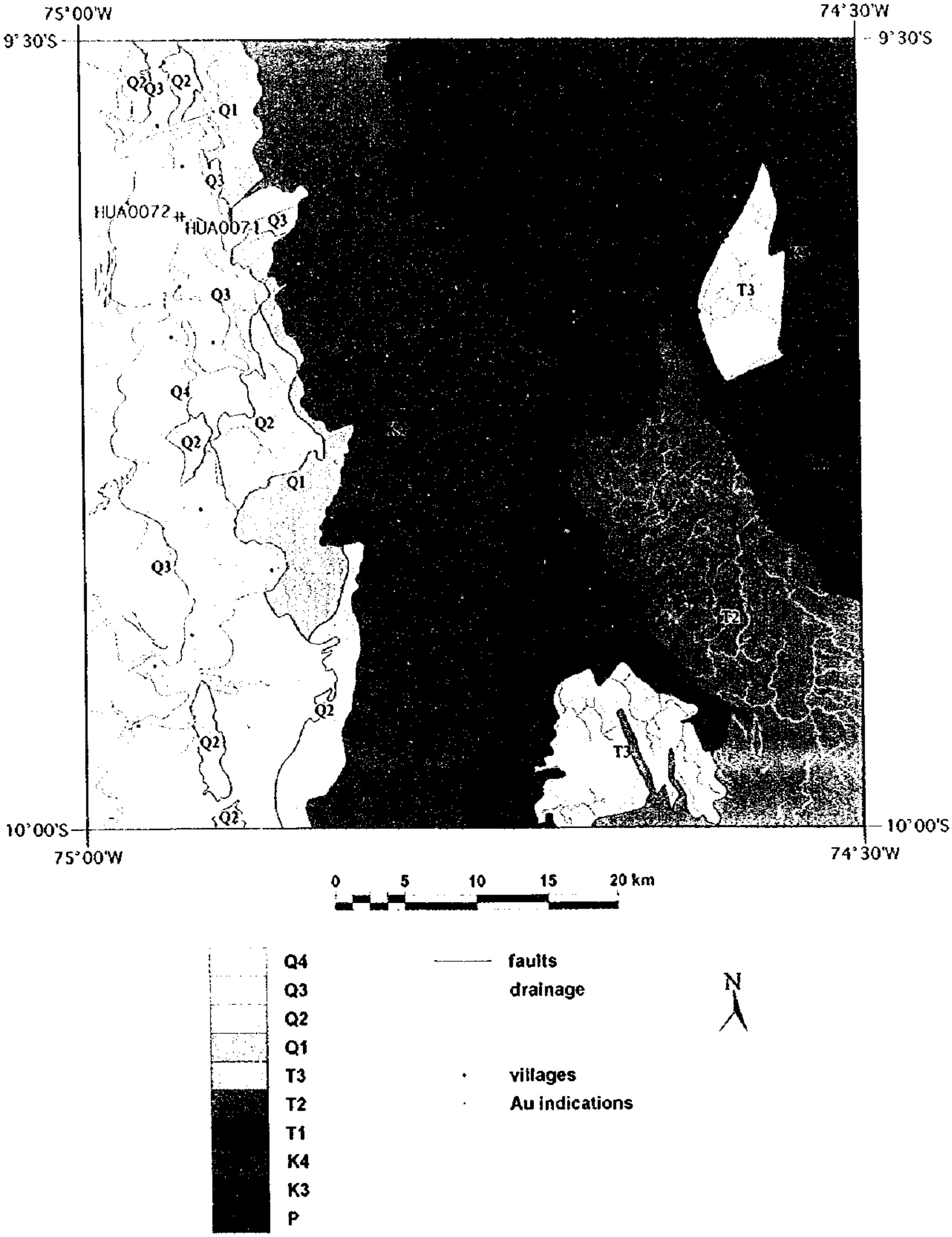


Figure 7-2 Yuyapichis (20-n) geologic interpretation map

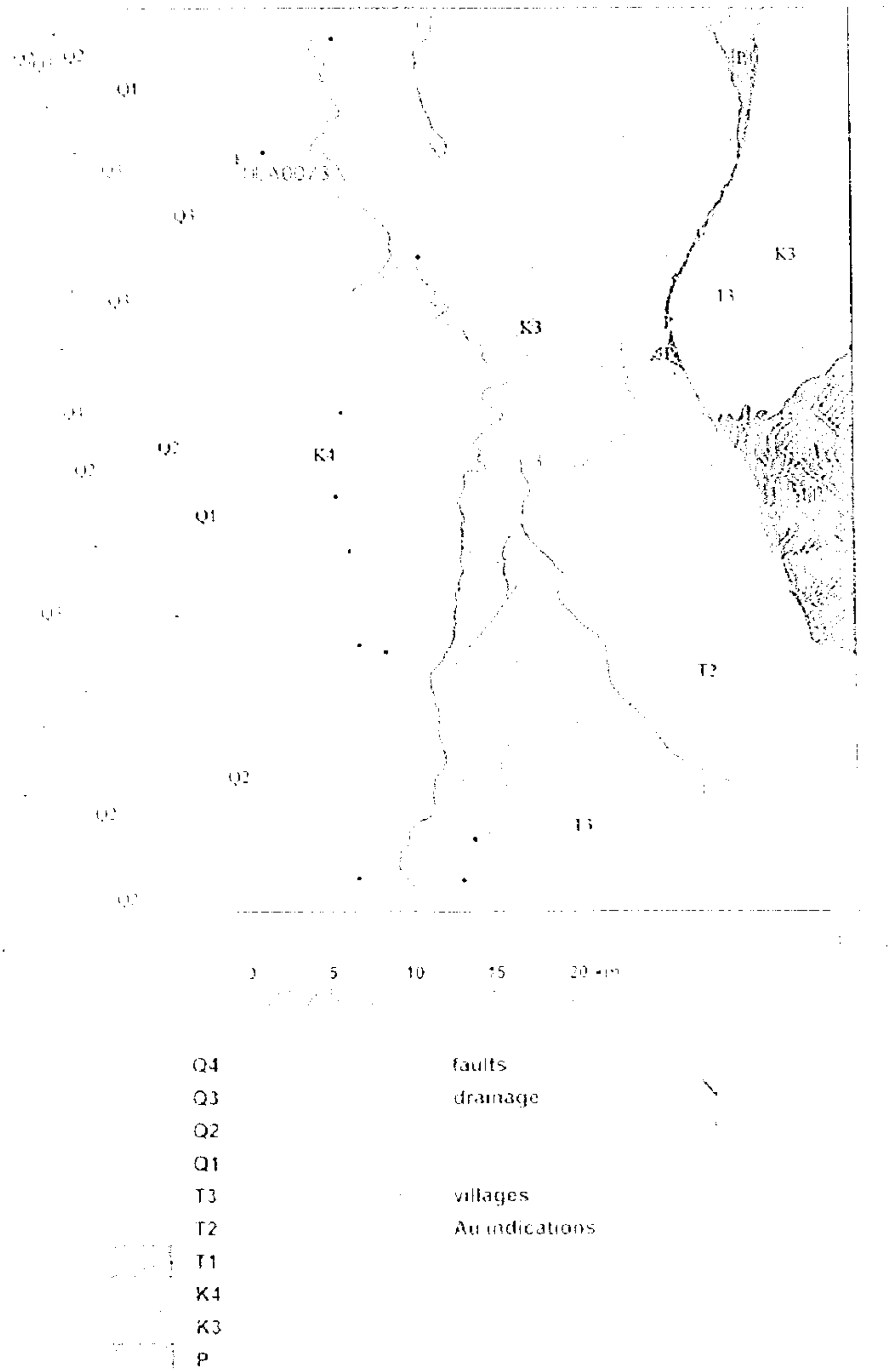


Figure 7-2 Yuyapichis (20-n) geologic interpretation map

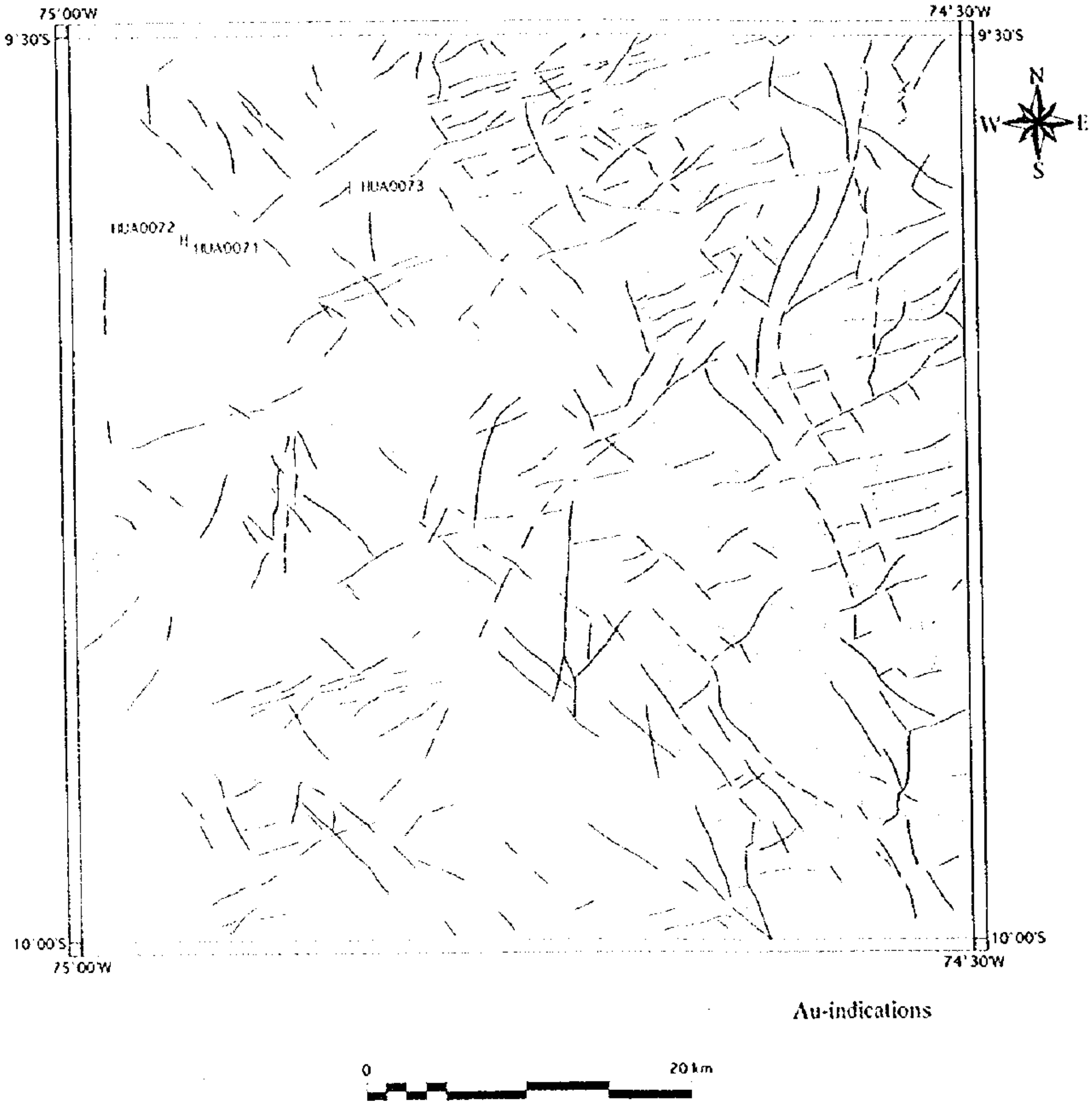


Figure 7-3 Yuyapichis (20-n) lineament map

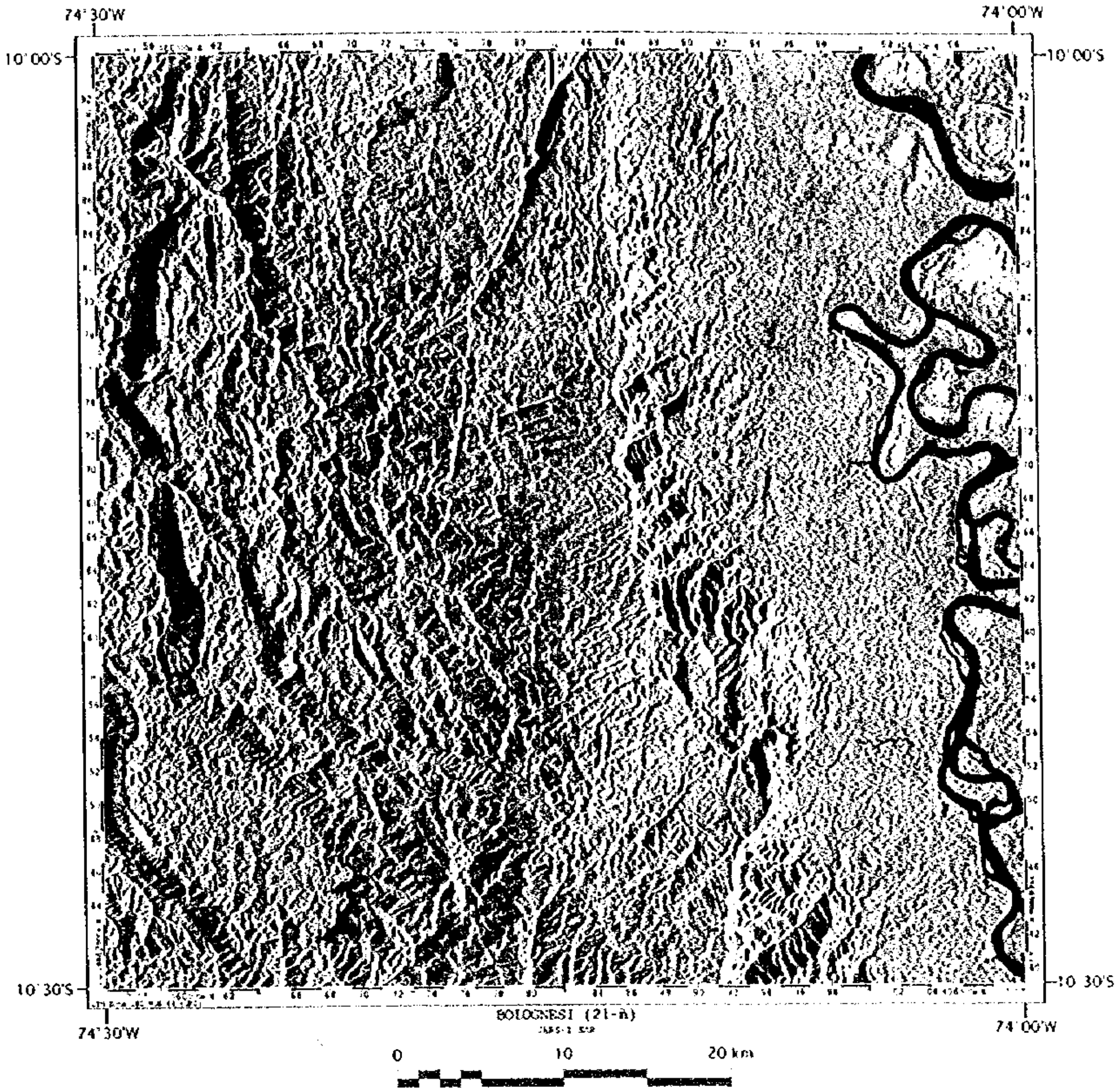


Figure 8-1 Bolognesi (21-ñ) JERS-1 SAR image

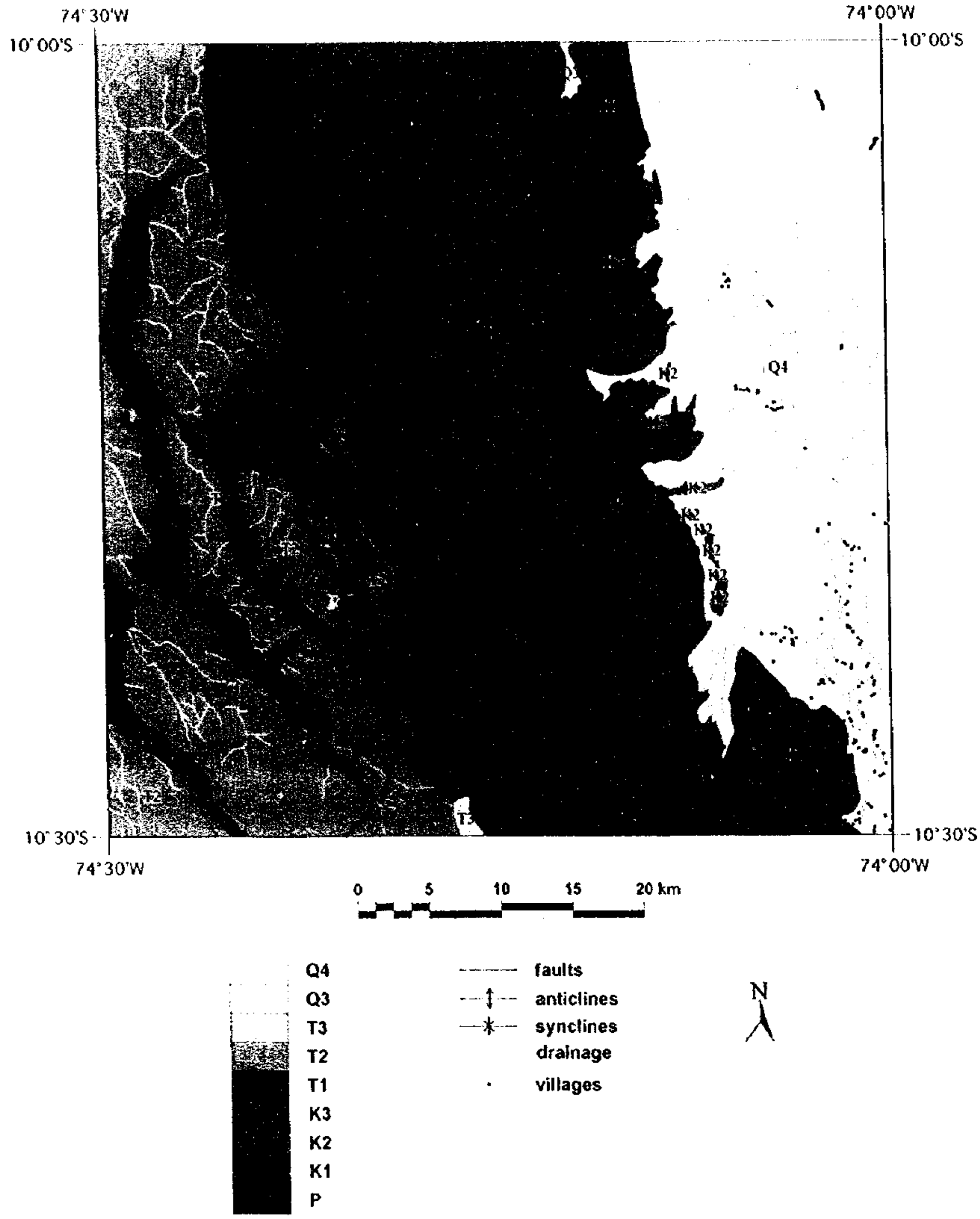


Figure 8-2 Bolognesi (21-ñ) geologic interpretation map

faults
anticlines
synclines
drainage
villages

Figure 8-3 Bolognesi (21-ñ) lineament map

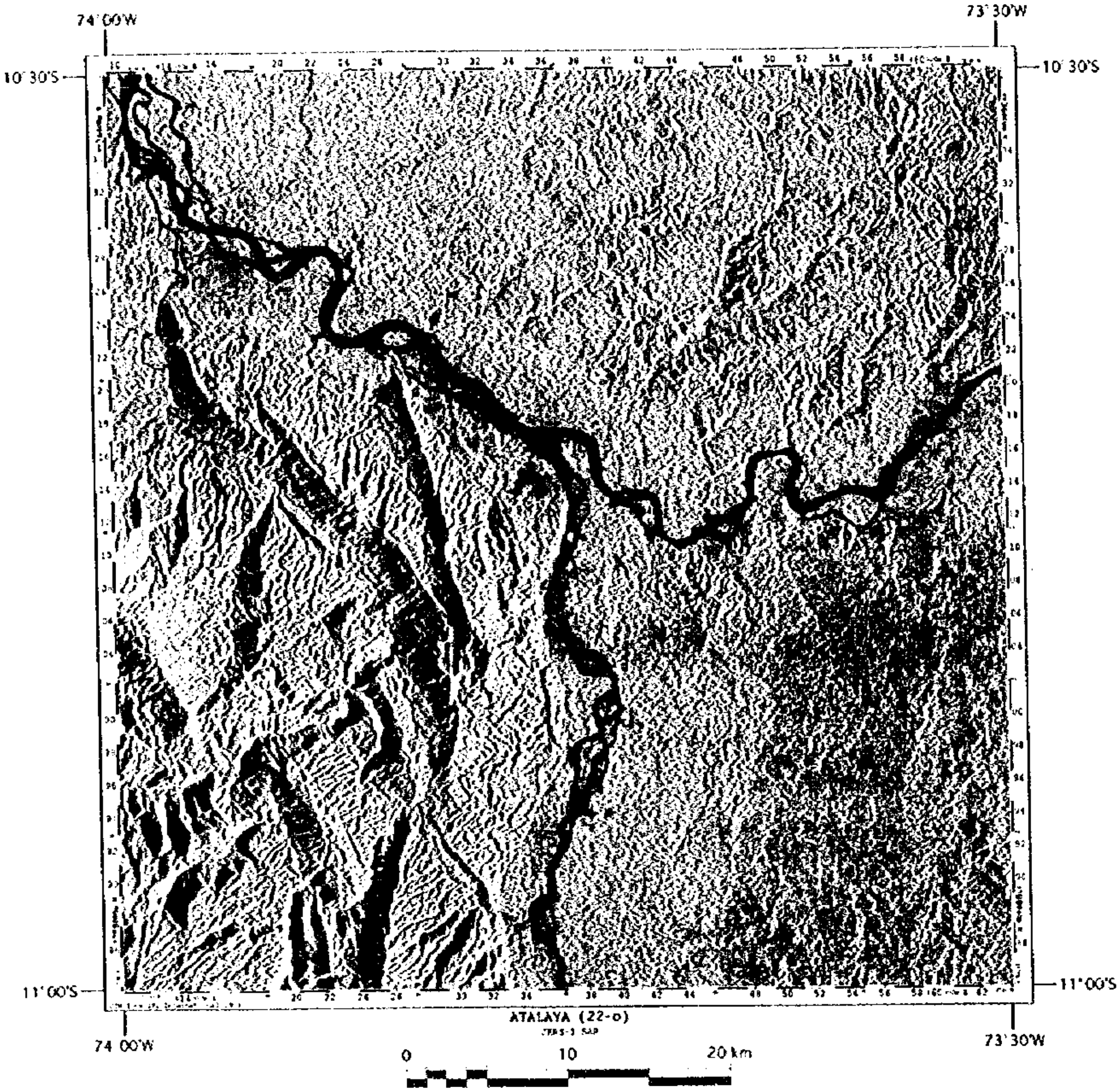
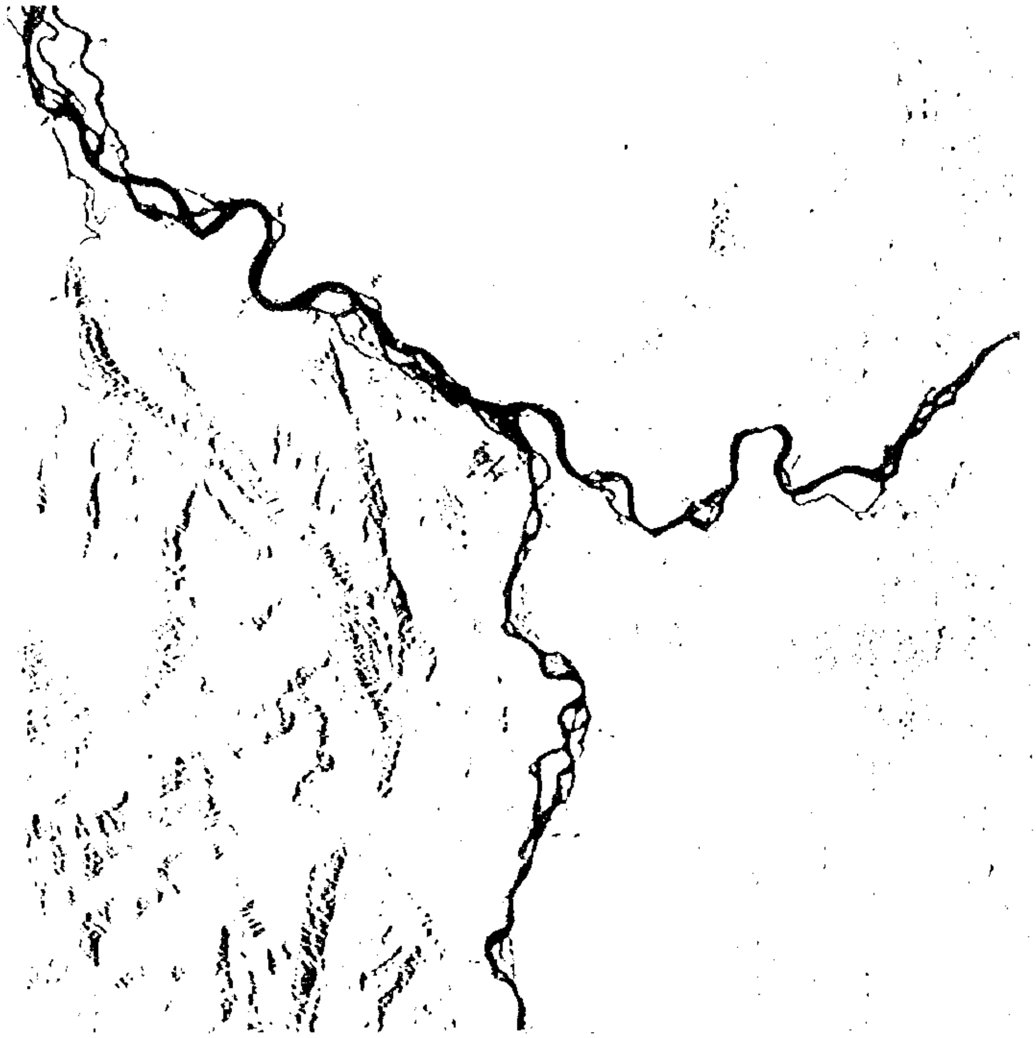


Figure 9-1 Atalaya (22-o) JERS-1 SAR image



[illegible] JERS-1 SAR image

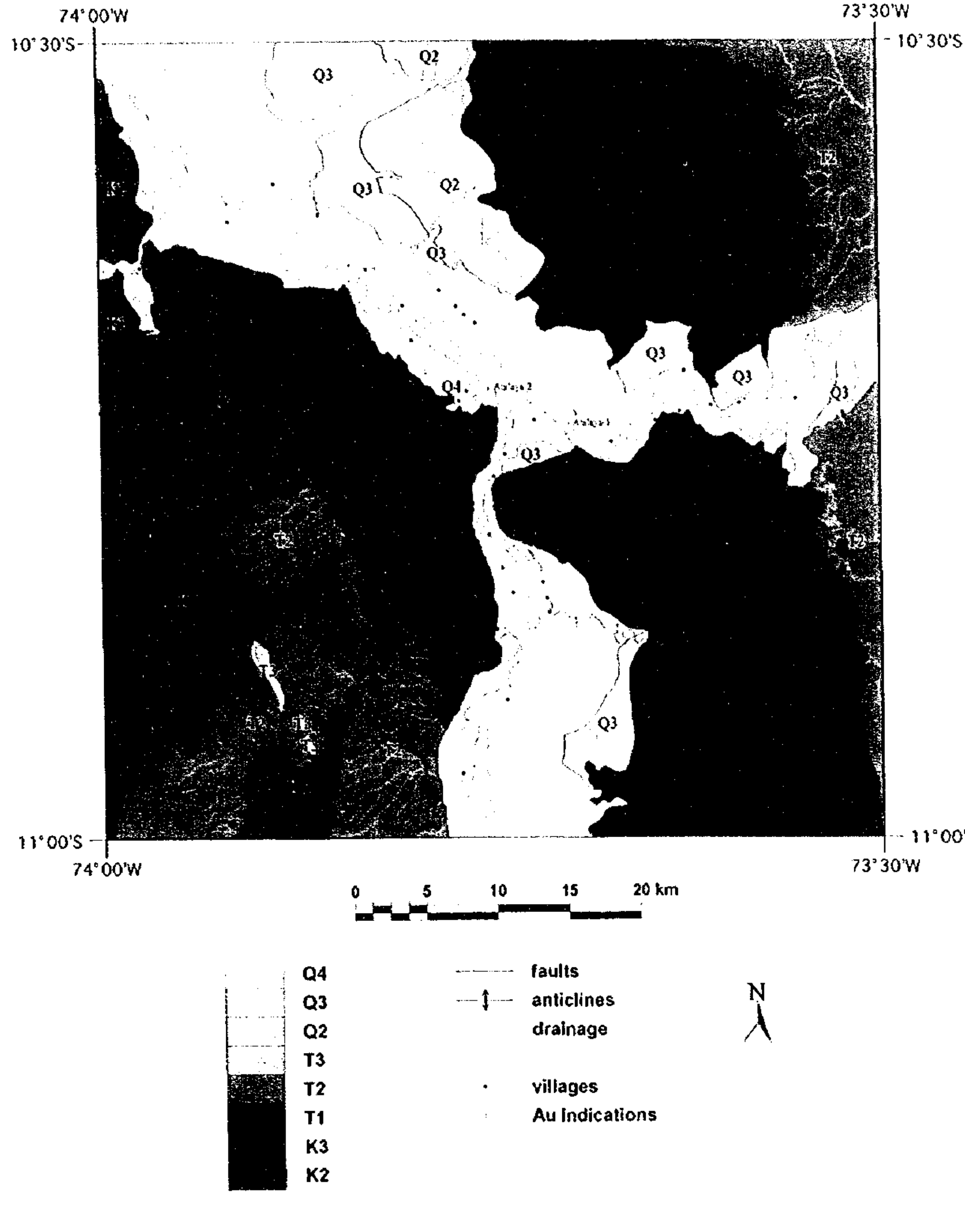
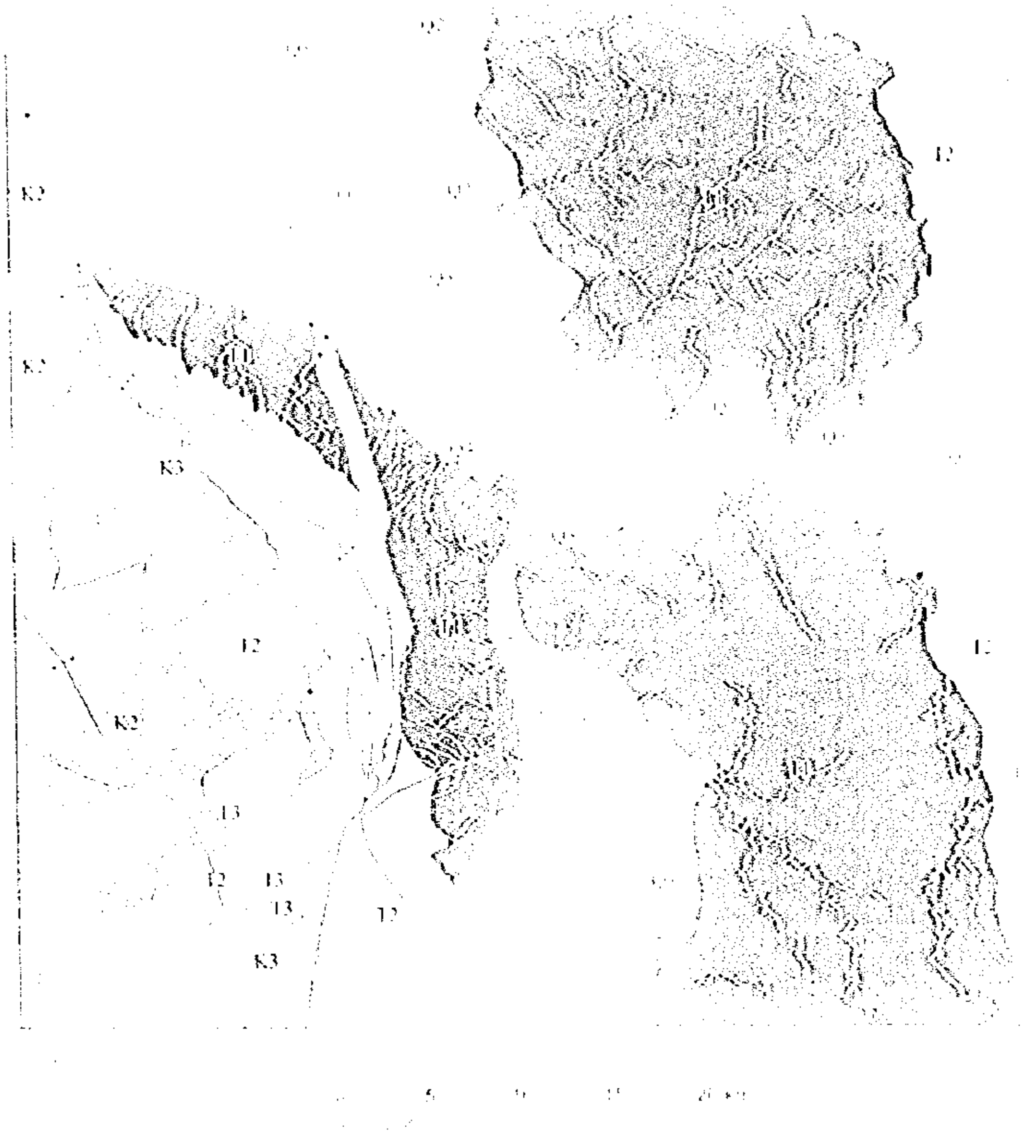


Figure 9-2 Atalaya (22-o) geologic interpretation map



Q4	faults
Q3	anticlines
Q2	drainage
T3	
T2	villages
T1	Accumulations
K3	
K2	

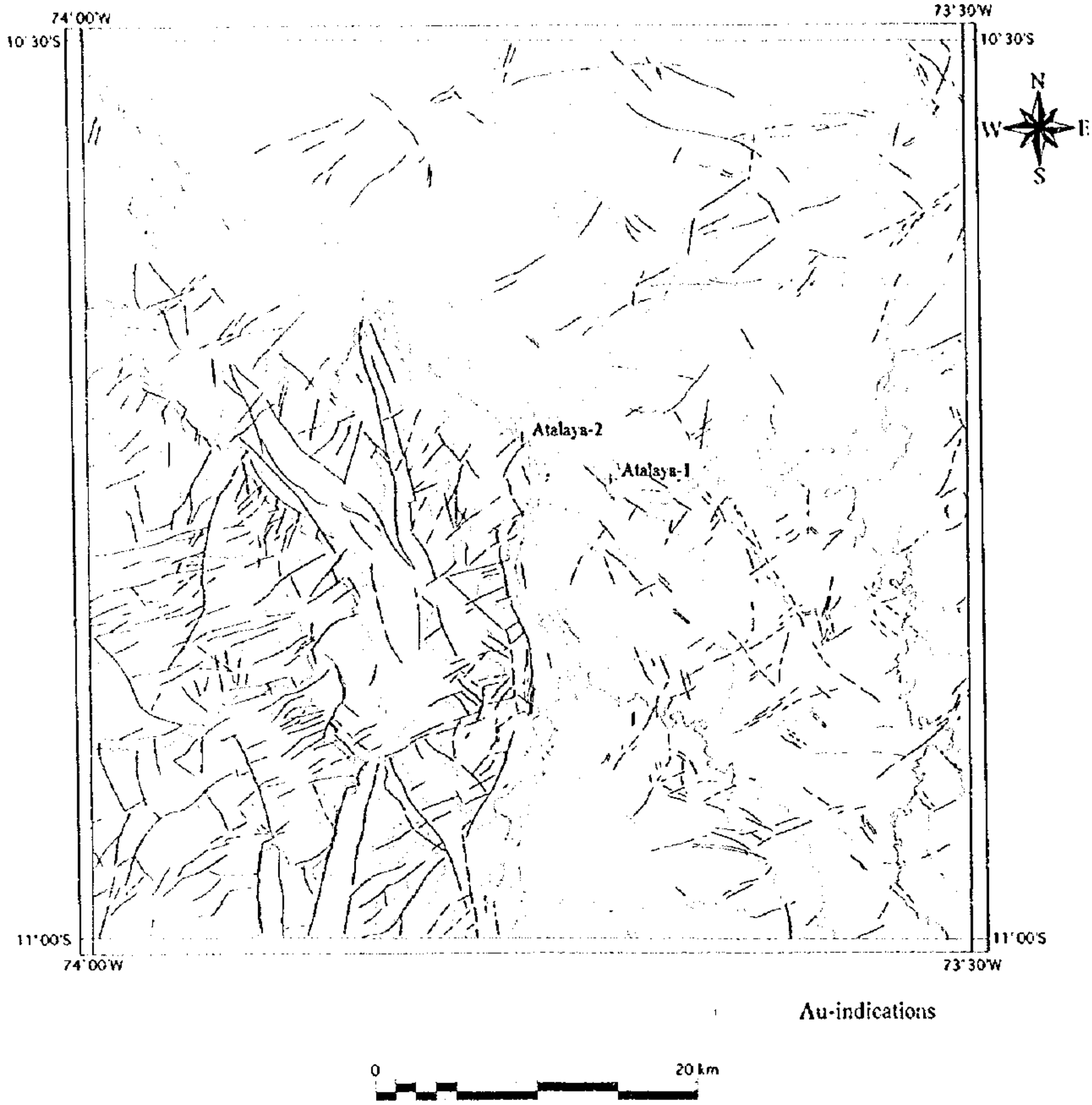


Figure 9-3 Atalaya (22-o) lineament map

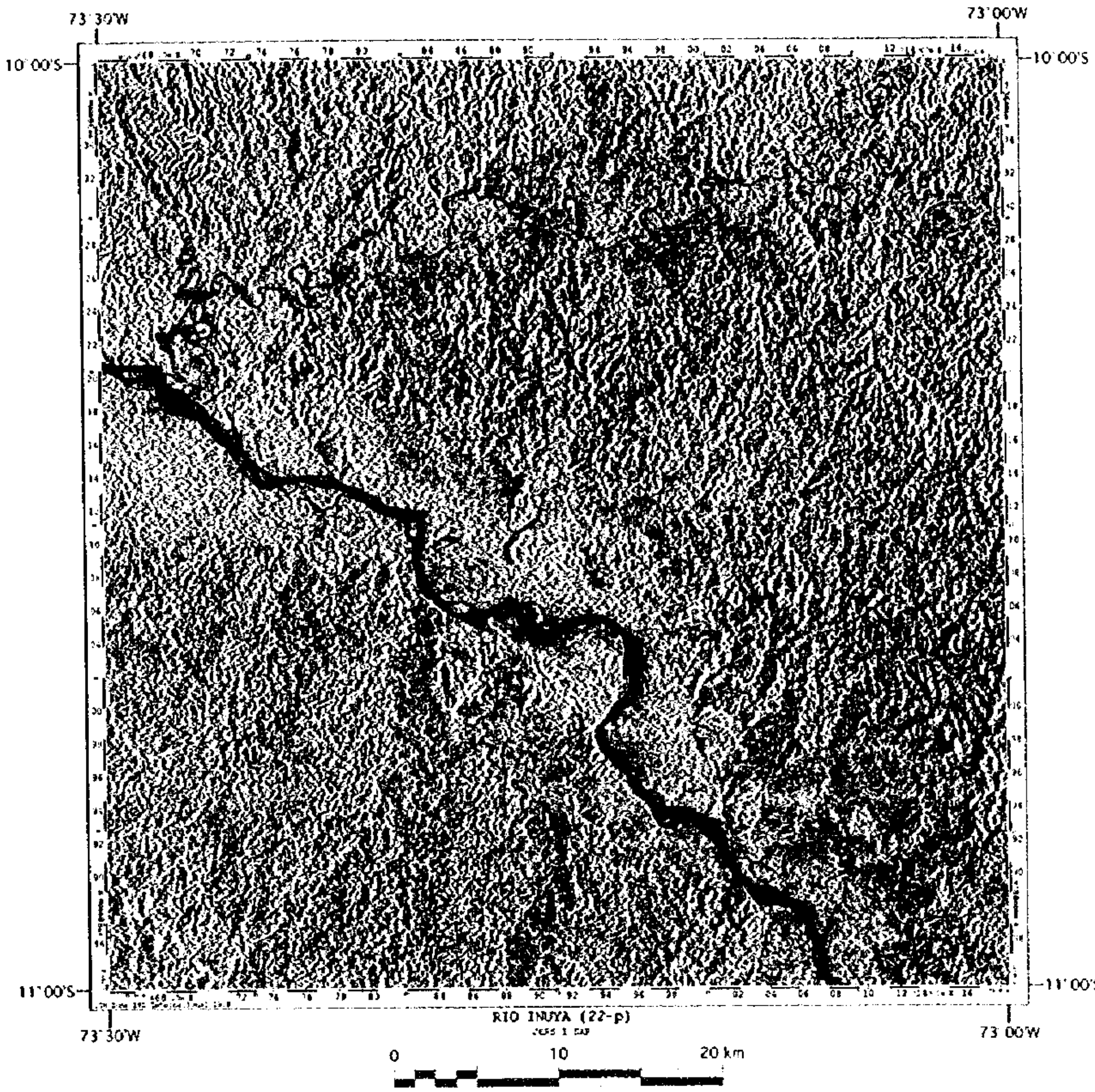


Figure 10-1 Río Inuya (22-p) JERS-1 SAR image

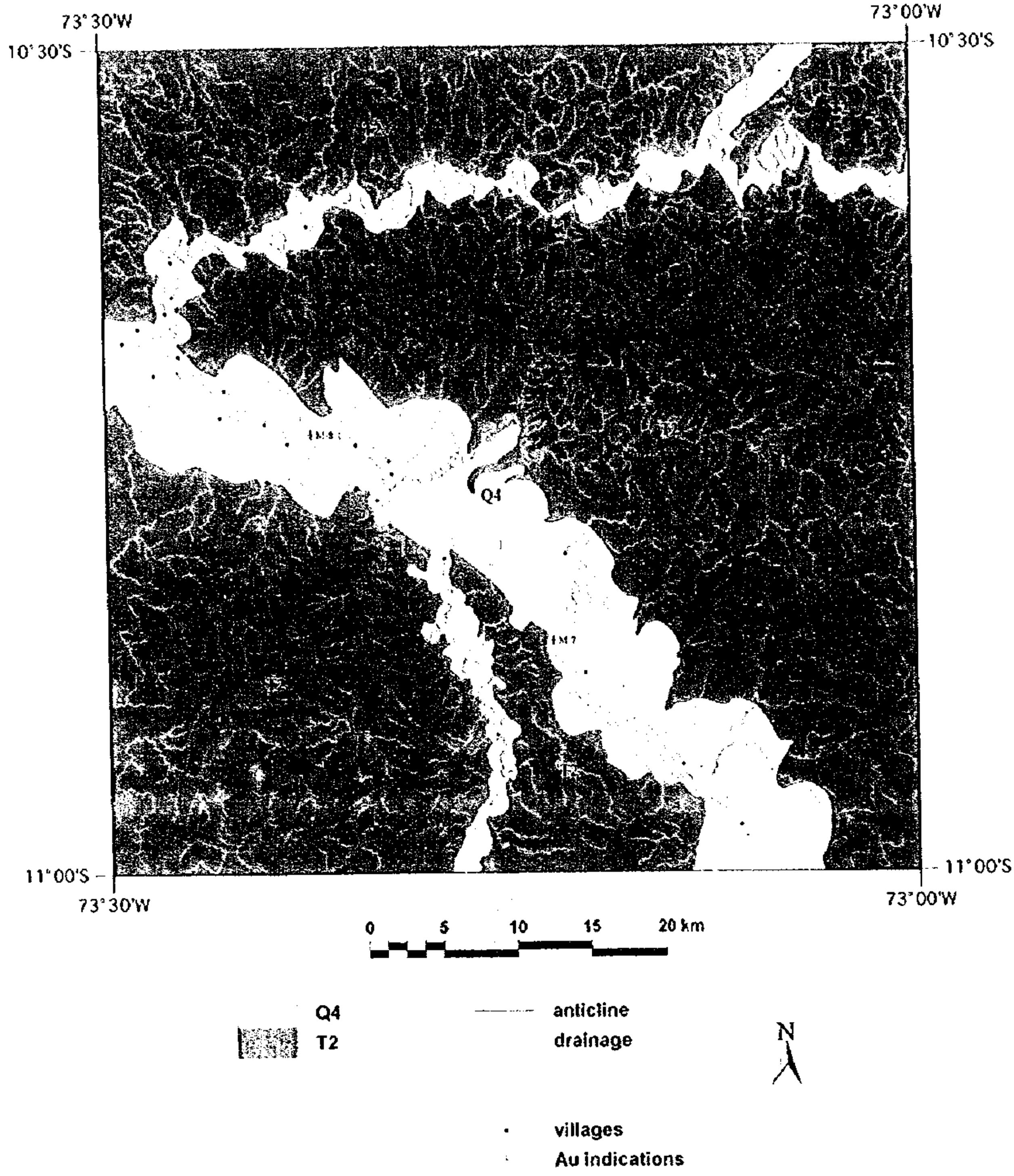


Figure 10-2 Río Inuya (22-p) geologic interpretation map

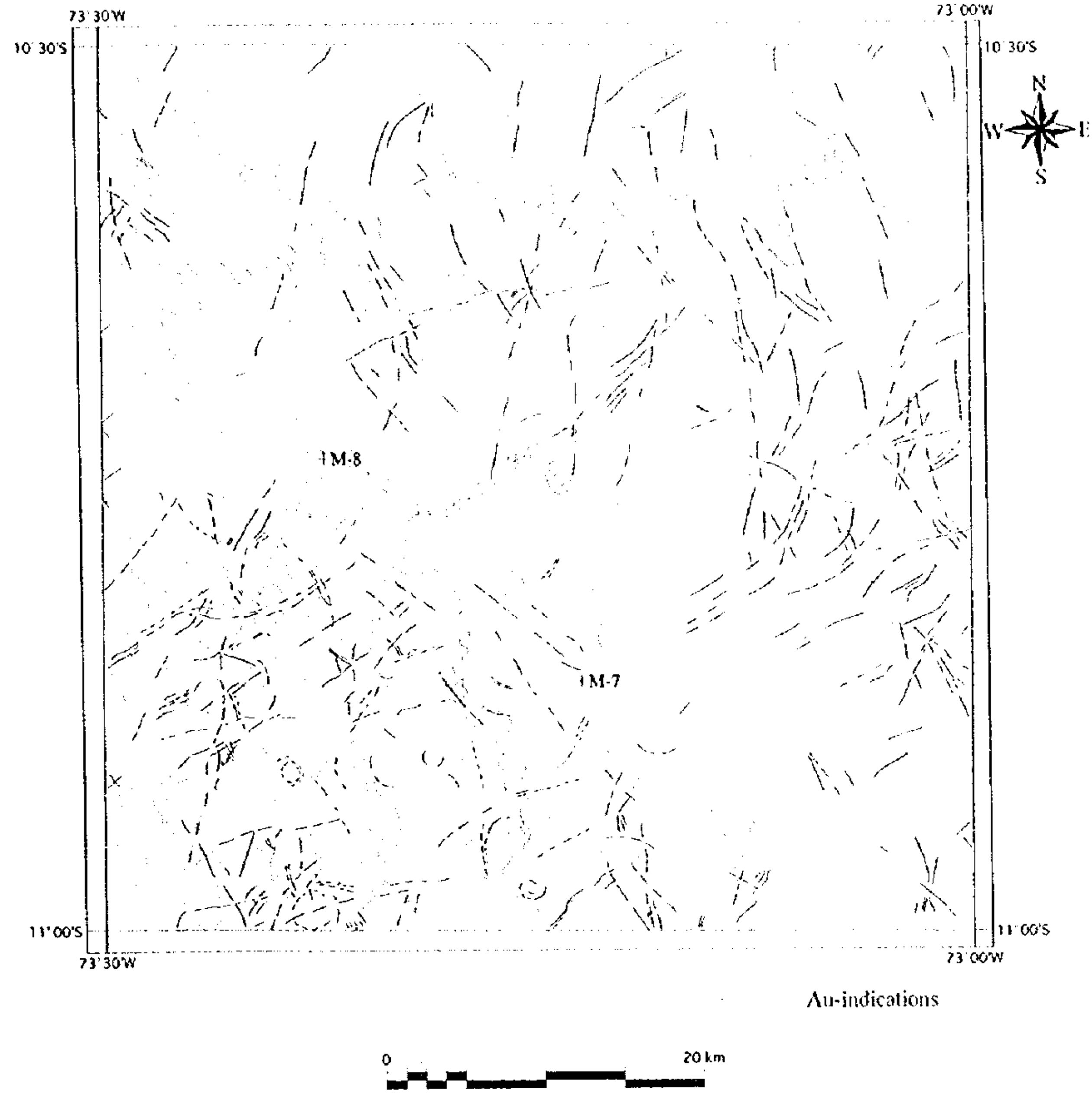


Figure 10-3 Río Inuya (22-p) lineament map

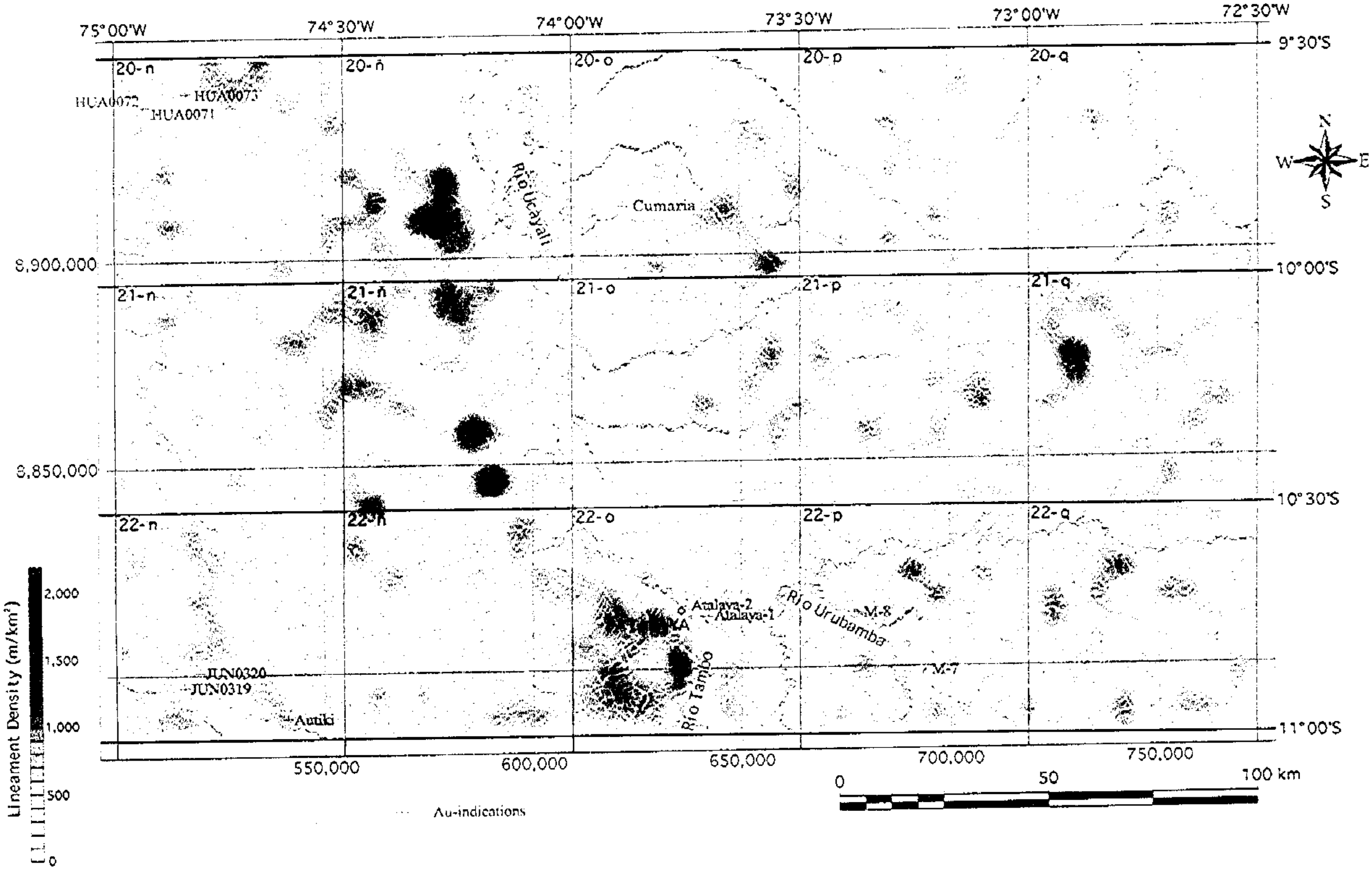


Figure 11 Lineament density map