REPUBLIC OF PERU

REPORT ON GEOLOGICAL SURVEY

OF

THE YAURI AREA, SOUTHERN PERU

Vol. II

Part 1. AERIAL PHOTOGRAPHY
Part 2. PHOTOGEOLOGY

November 1972

OVERSEAS TECHNICAL COOPERATION AGENCY
METALLIC MINERALS EXPLORATION AGENCY
GOVERNMENT OF JAPAN

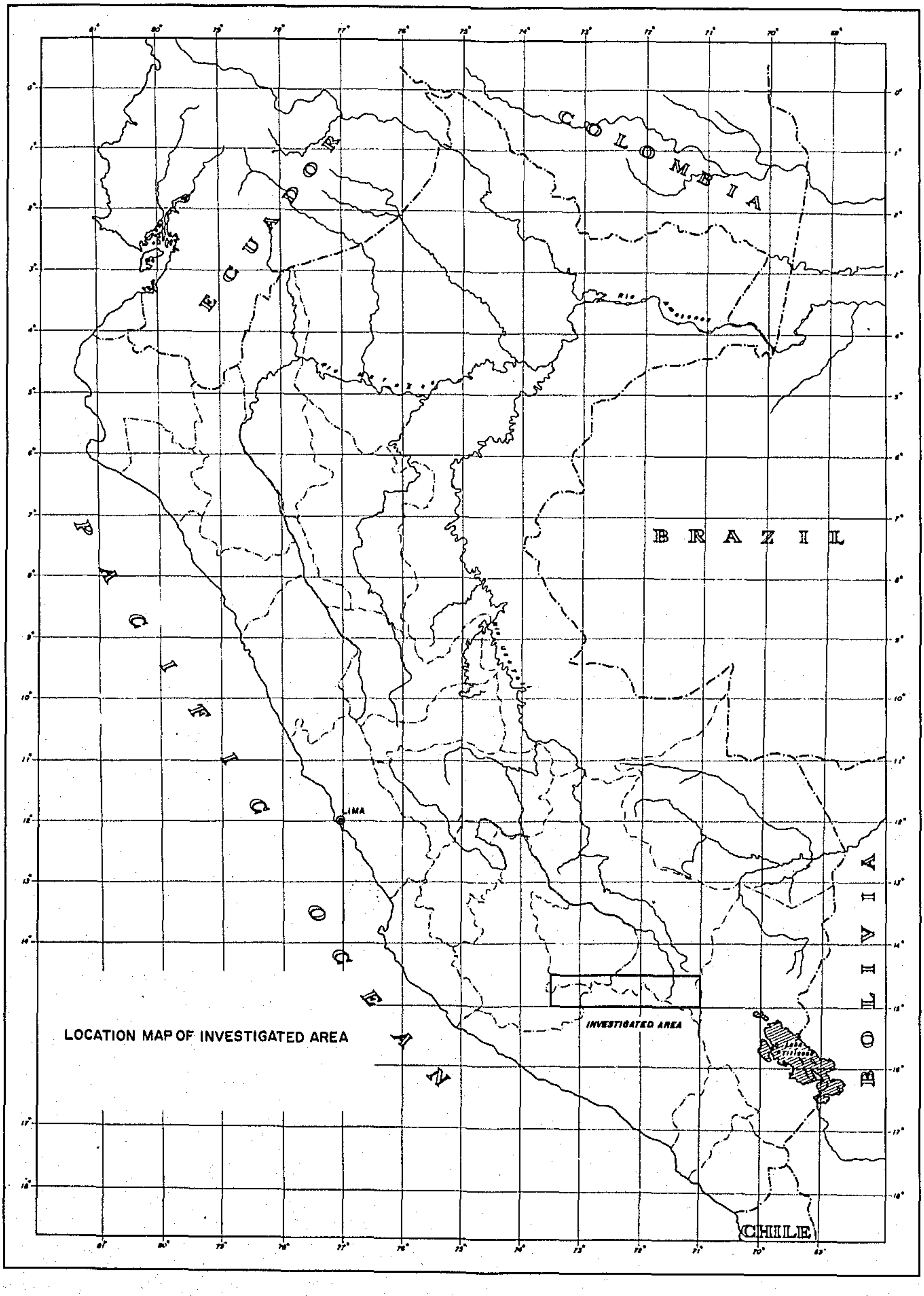
REPUBLIC OF PERU
REPORT ON GEOLOGICAL SURVEY
OF
THE YAURI AREA, SOUTHERN PERU

Vol. II

Part 1. AERIAL PHOTOGRAPHY
Part 2. PHOTOGEOLOGY

November 1972

OVERSEAS TECHNICAL COOPERATION AGENCY
METALLIC MINERALS EXPLORATION AGENCY
GOVERNMENT OF JAPAN



LOCATION MAP OF INVESTIGATED AREA

Part 1. AERIAL PHOTOGRAPHY

CONTENTS

1. PHOTOGRAPHED AREA

The photographed area, covering the entire project of 14,750 km^2 is bounded by the following grids:

Northern margin	Latitude 14°30' south
Southern margin	Latitude 15°00' south
Eastern margin	Longitude 71°00' west
Western margin	Longitude 73°30' west

2. FLIGHT PLAN

2-1 Airport

The best possible location for a base was pre-determined to be Arequipa, which is located south of the project area.

2-2 Flight Direction

The narrow elongated shape of the area dictated the flight direction, consequently ten E-W lines were flight planned providing a side overlap of 32% at an average terrain elevation of 4800 meters.

2-3 Selection of Aerial Camera

The average terrain elevation was calculated to be 4800 meters. Since the scale of photography was to be 1:40,000 the service ceilings of aircraft in current use had to be considered. Therefore, a turbo Aztec was chosen to provide a platform for a Zeiss RMK 8.5/23 super wide camera.

2-4 Flight Altitude

The area is extremely mountainous with high ridges and narrow valleys running in a NNW-SSE direction. The eastern part of the area is situated in the "alto-plano" region of Peru having an elevation of approximately 3900 meters. The western portion of the area is extremely mountainous with glacial peaks to 5300 meters. The area is scarred by deep gorges and narrow valleys. The average terrain was calculated at 4800 meters and flying height was established at 8300 meters.

3. EXECUTION OF PHOTOGRAPHY

3-1 Airport

The Arequipa airport was used for a base as planned.

3-2 Equipment

(1) Aerial Camera

Name: Zeiss RMK 8.5/23

Lens: Super wide angle

Focal Length: 85 mm

Filter: Minus blue

(2) Film

Kodak Aero Colour Negative No. 2445

(3) Airplane

Turbo Aztec CF-ULL

3-3 Photography

As scheduled, 10 lines in an E-W direction were photographed.

(1) Length of Lines

All lines were 270 km in length for a total of 2700 km.

(2) Scale

An average of 1:40,000

(3) Forward overlap: 80%

(4) Lateral overlap: 32%

(5) Exposure: F4 1/300 and 1/400

(6) Navigation: Visual

4. *WEATHER CONDITIONS*

The photography was started on August 10, 1971 which is rather late in the photo season for this area. Although the aircraft was ready to proceed on site the 20th of July, 1971, there was a delay in the issuance of permits by the Peruvian authorities. The contract extended into the bad weather conditions of October and November. There were two cloud gaps, however because of the late period in the photo season these gaps were left unfinished.

5. FILM PROCESS

The exposed film was shipped to Canada and processed in the Canadian Government photo laboratory at the Canadian Forces Base, Rockcliffe, Ontario. This was necessary as there were no local facilities available for this particular type of film. Printing was done by Geoterrex Limited of Ottawa, Ontario.

Part 2. PHOTOGEOLOGY

CONTENTS

List of Figures

List of Attached Maps

1. CONCLUSIONS AND RECOMMENDATIONS

1-1 Conclusions

1) A photogeological laboratory study of an area of about 15,000 km^2 in Yauri territory in south Peru was carried out to obtain basic data for developing mineral resources. The results are presented in this report. The main purpose of this study is to complete the drainage pattern maps which will be used for the basic topographic maps and to compile photogeological maps by photo interpretation.

2) South Peru can be divided roughly into the following geomorphologic-structural zones;

   (1) Coast of the mountain rainge

   (2) Coastal lowland and depression

   (3) Western mountains

   (4) Chain of volcanic cones

   (5) Valleys and regions between mountains

   (6) Titicaca basin

   (7) Eastern mountains.

   The project area is situated in the (3) Western mountains.

3) The project area consists mainly of upper Jurassic-Cretaceous sediments, lower Cretaceous-upper Tertiary intrusive rocks and Tertiary-Quaternary sediments and volcanics. Moreover, glacial deposits and fluvio-glacial deposits occur in many places of the area. In these rocks, Tertiary-Quaternary volcanics occupy more than 95% of the western-middle project area and more than 70% of the eastern project area.

4) The intrusive rocks mainly occur in the eastern part of the project area and are overlain by the Mesozoic sediments as the Roof-Pendant. The basalt dykes are intruded into the Tertiary-Quaternary volcanics in the western-middle part of the project area.

5) The project area is characterized by a distinguished geological structure of Peru which trends in the NNW-SSE direction. Namely, the most important is (1) the arrangements of the lithofacies, (2) the elongated direction of faults (3) and of folding axes and (4) the direction of minor fractures in this area seem to trend mainly in the NNW-SSE direction.

6) The elongated direction of faults and the folding axes, however, are different in the rock forming age. It may suggest that the geotectonic movements in this area are somewhat different from those in another age.

7) Though the faults in the area show a predominantly NNW-SSE trend trending to strike parallel, they also are slightly different in the rock forming age and may support the idea mentioned in paragraph 6).

1-2 Recommendations

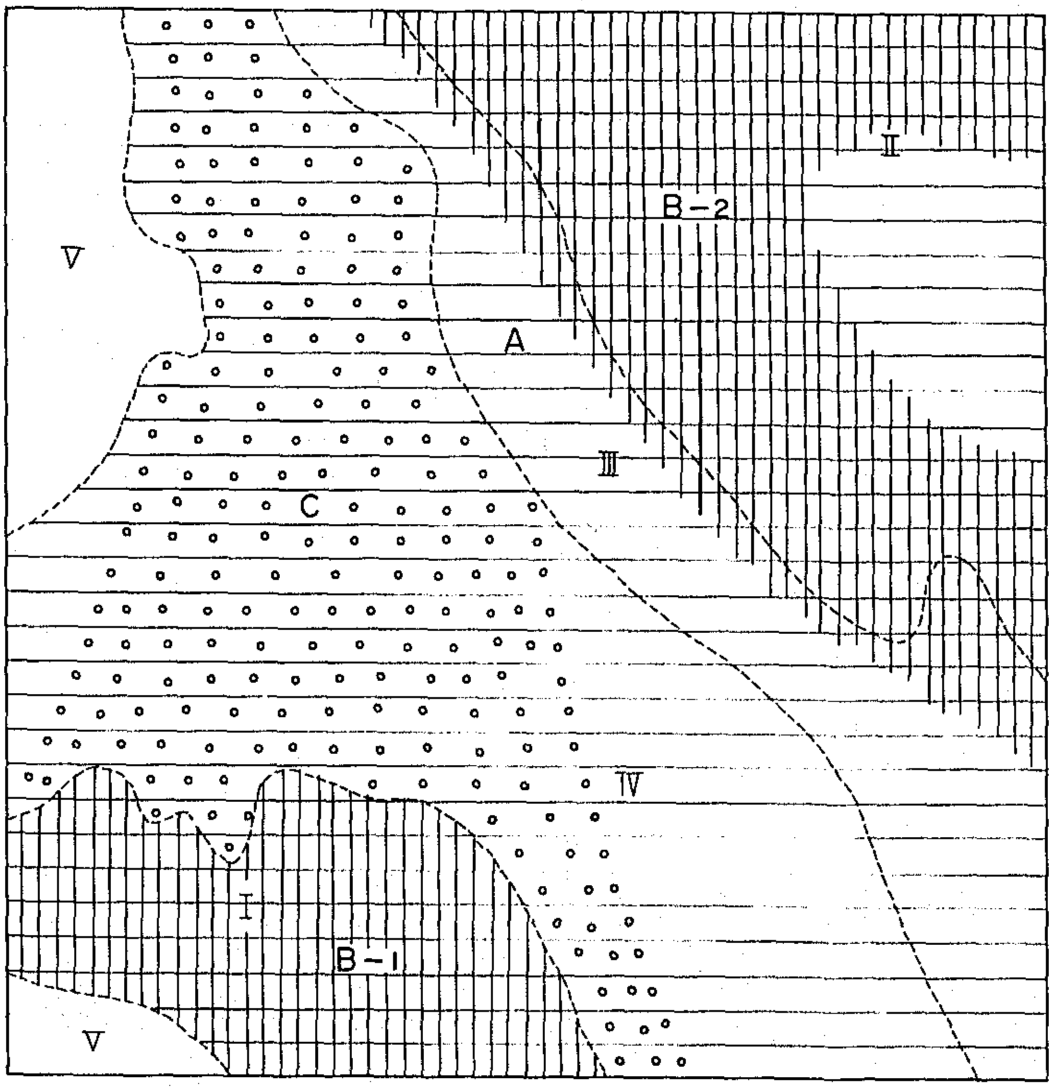
1) According to the results of this study, the possibility of having mineral resources is extremely low in the western-middle part of the project area (sheet No. 1-3), but high in the eastern part of the area (sheet No. 4 and 5) because the limestone and granitic rocks intruded into limestone etc. is closely related to mineral resources. Therefore, further investigations should be limited to the eastern part of the project area (mainly the eastern part of sheet No. 4, and sheet No. 5).

2) Namely, a semi-regional study is reocmmended in the eastern project area, mainly in the area of sheet No. 5 (at least A block shown in Fig. 1).

3) Detailed field investigations and mapping should be carried out in the area where the igneous rocks have intruded into the upper Jurassic-middle Cretaceous sediments and in the controlling zones such as faults or sheared zones. Especially, detailed studies along major faults should be carried out in these zones.

4) There is a question in the reason for the folding structure of unit 16 (white tuff etc.). Therefore, the rock facies and depth of the basement rocks in the adjoining area of B-1 in unit 16 should be clarified by magnetic surveys or other methods.

5) Semi-regional investigations in the northern side of B-2 (Fig. 1) are necessary since the relationship between unit 4 and unit 5 could not be clarified and the rock facies of unit 5 have not been confirmed by the field investigations for this study.



Geology

I Upper Jurassic – Middle Cretaceous Area
II Upper Cretaceous Area
III Tertiary Area
IV Quaternary Area
} Sedimentary Rock Area

V Volcanic or Intrusive Rock Area

Recomendation

A Semi-regional Investigation Area

B Detailed Field Mapping Area

C Area where Basal Rocks should be Clarify by Airbone Magnetics etc.

Fig. I MAP SHOWING THE RECOMMENDED AREA FOR FURTHER INVESTIGATION (SHEET NO.5)

2. PROCEDURE OF WORK

2-1 General Procedure

Photogeological investigation is one of the geological survey methods and is effective for general and regional geological mapping as the preliminary process for detailed geological mapping and study. This method is performed through the process of study of existing geological data, photointerpretation and making observations and checks in the field.

Photographic elements such as tone, tonal texture, color, linear pattern, topographic expression (drainage pattern, microtopography, surface shapes and so on), are interpreted in order to obtain information concerning the lithological character and the geological structure by using stereo-paired aerial photographs.

Though a specialized photogeological working process can be adopted, the results strongly depend on the quality and quantity of the existing data, the quality of photographic information which is remarkably dominated by a condition of the photoimages, the photo scale, the characteristics of the investigated area, and on the experience of the interpreter. These factors also affect the ratio between the laboratory and field study.

The following operation flow is generally adopted in order to perform the photogeological study effectively as shown in Fig. 2.

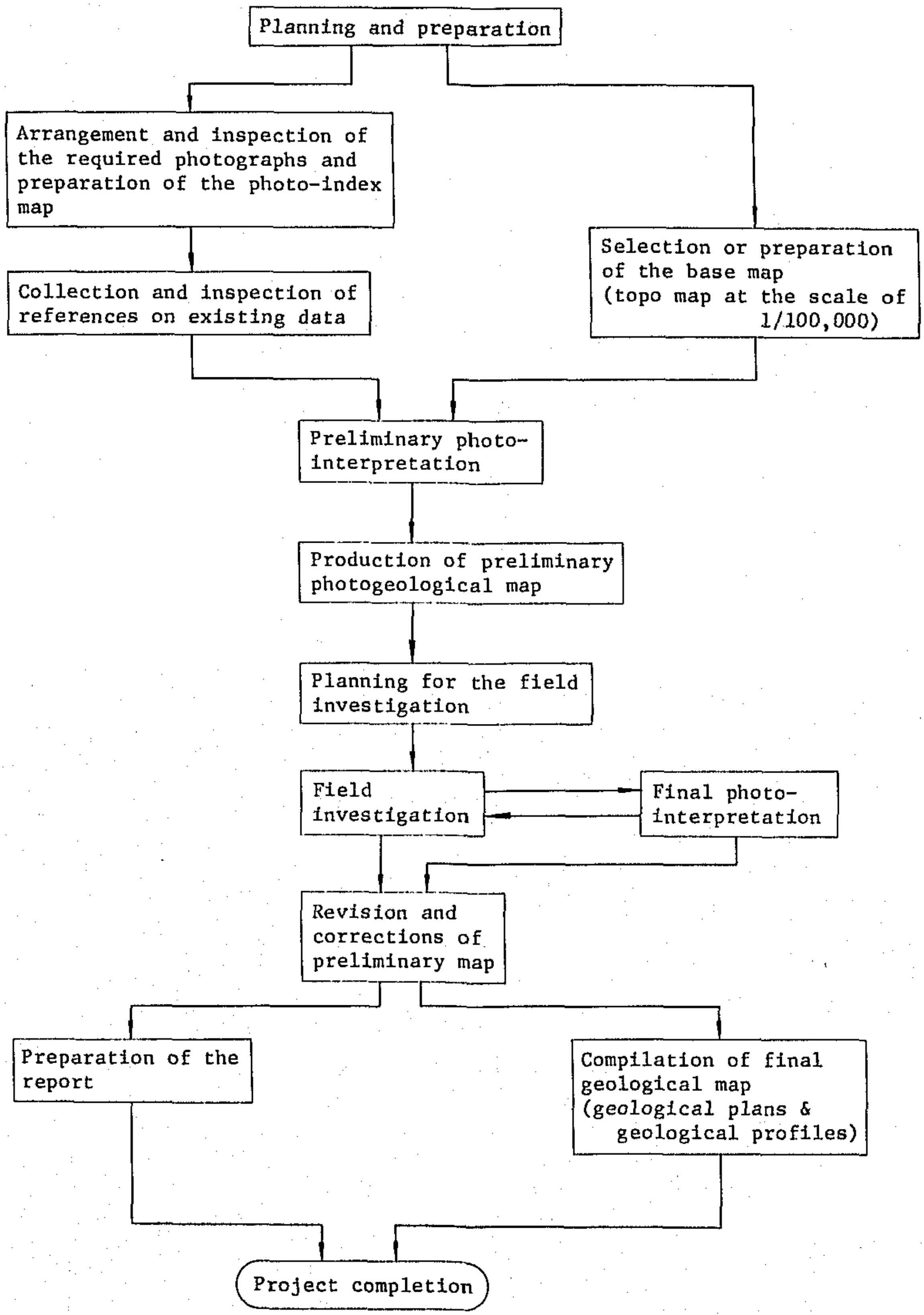


Fig. 2 General flow chart for the photogeological investigation

2-2 Procedure in this Project

2-2-1 Project Area

The area covered by this photogeological investigation occupies the below mentioned area of approximately 14750 km^2.

Northern margin	Latitude	14°30' south
Southern margin	Latitude	15°00' south
Eastern margin	Longitude	71°00' west
Western margin	Longitude	73°30' west

2-2-2 Photographs and Topographic maps used

The following aerial photographs and topographic maps were available for this work.

(1) Aerial photographs

Date of photography	; 1971
Photo scale	; 1:40,000 (approximately)
Number of contact prints	; about 800

(2) Topographic maps

1) 1:100,000

Date issued ; 1969

Number of sheets ; 3

Sheet	W.	S.
Pacapausa	73°00' - 73°30'	14°30' - 15°00'
Velille	71°30' - 72°00'	14°30' - 15°00'
Yauri	71°00' - 71°30'	14°30' - 15°00'

Issuing organization; Instituto Geographico Milital, Peru

2) 1:200,000

Date issued ; 1941, 1945, 1965

Number of sheets ; 5

Sheet	W.	S.
Coracora	73°12' - 73°48'	14°24' - 15°12'
Alca	72°36' - 73°12'	14°24' - 15°12'
Sto Tomas	72°00' - 72°36'	14°24' - 15°12'
Yauri	71°24' - 72°00'	14°24' - 15°12'
Macari	70°48' - 71°24'	14°24' - 15°12'

Issuing organization; Instituto Geographico
Milital, Peru

(3) Photomosaics

Date issued	;	1968, 1969
Photoscale	;	1:100,000
Number of sheets	;	3 Cayarani (W. 72°00' - 72°30', S. 14°30' - 15°00') Velille (W. 71°30' - 72°00', S. 14°30' - 15°00') Yauri (W. 71°00' - 71°30', S. 14°30' - 15°00')
Issuing organization	;	Instituto Geographico Milital, Peru

Prior to the preparation of photogeological laboratory study, the aerial photographing, mentioned above, field geological investigations and aeromagnetic surveys were carried out by other investigation teams. The geological route-maps prepared by the field geological investigation team and the interim results of the aeromagnetic surveys were used for this geological interpretation study.

A systematic regional geological investigation has not been adopted in this project area. As shown in Fig. 3, this working process is slightly different in some respects from the general flow shown in Fig. 2 as follows.

1) Three fifths of this project area is covered by topographic maps at 1:100,000 scale and these are suitable base maps for this study. Since two fifths of this area, however, is only covered by topographic maps at 1:200,000 scale which are not suitable for this study, the existing photomosaics and newly compiled uncontrolled photomosaics area used as a substitute for the base map.

2) The drainage pattern maps compiled from the photomosaics served as the base map for the photogeological maps.

3) The photogeological interpretation and the field investigations were carried out independently of each other and the drainage pattern maps and photogeological maps were compiled only by photo-interpretation.

The fragmentary descriptions and sparse geological maps of small scale (1:1,000,000) were the only data available. These data concerning the study are listed at the end of this report. However, most available data were route-maps prepared by the field geological investigation team.

In regard to this project area, thin vegetation cover due to high elevation made detailed geological interpretation easy and improved the accuracy of the interpretation. Therefore, the phtogeological maps compiled in this study are considered to be of high quality.

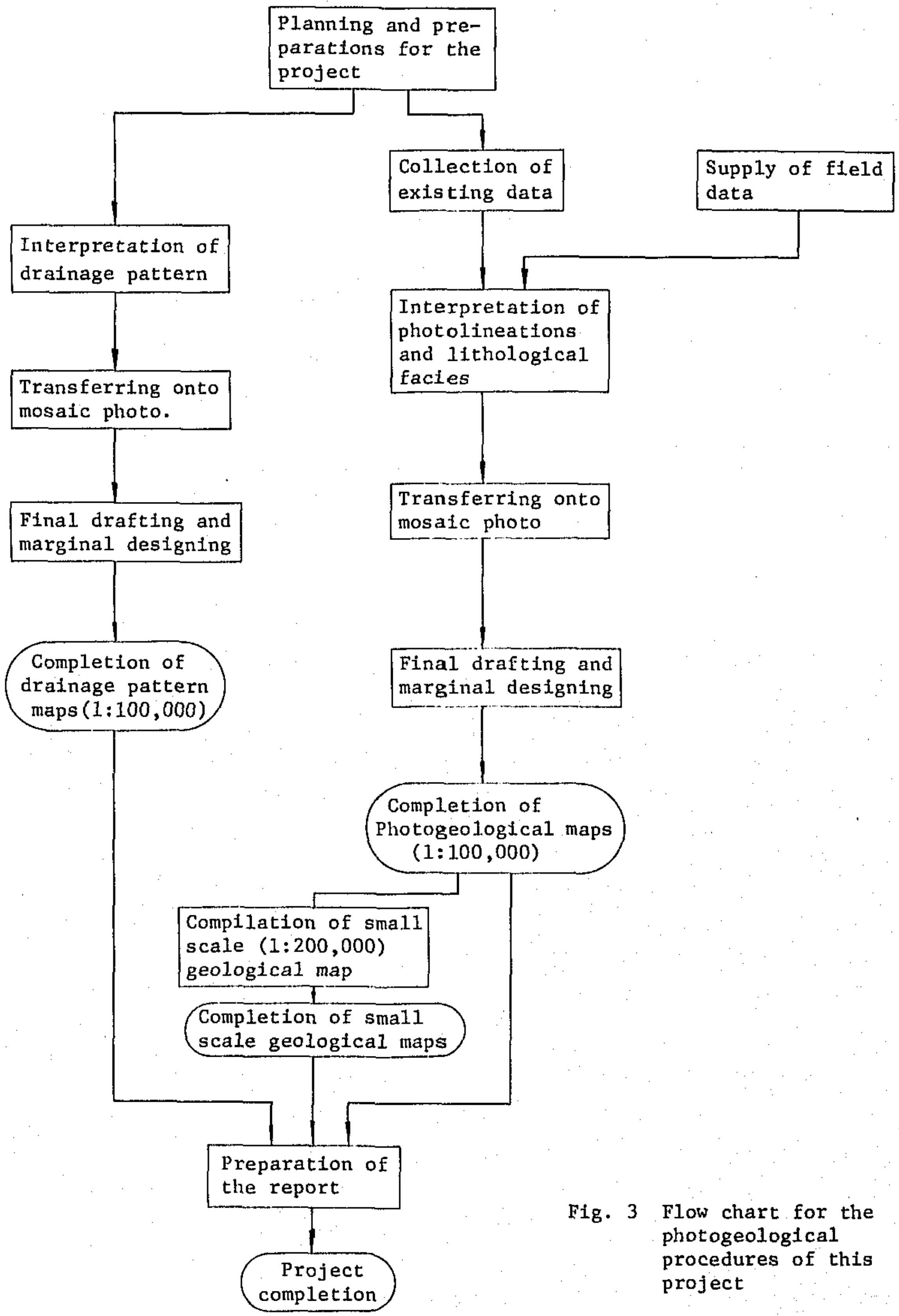


Fig. 3 Flow chart for the photogeological procedures of this project

3. GENERAL TOPOGRAPHY

Morphologically and structually, the Peru territory can be divided into the following 10 zones (Mines terio de Energia y Minas; 1969).

(1) Coast of the mountain range

(2) Coastal lowland and depression

(3) Western mountains

(3a) Chain of volcanic cones

(4) Valleys and regions between mountains

(5) Titicaca basin

(6) Eastern mountains

(7) Subandia mountains

(8) Amazon lowland

(8a) Shira mountains

The project area is situates in the (3) Western mountains divided above south Peru (Fig. 4) and can be divided topographically as follows (Fig. 5):

(1) Western-central Mountainous division

(2) Eastern Basin division

(3) Eastern Mountainous division

3-1 Western-central Mountainous division

The western-central part of the project area: viz. westside of Rio Velille basin, is a high area which has many mountains of 4600 - 5300 m in elevation such as the Co. Condorillo (4679 m), Co. Pabellones (4943 m), Co. Tantajara (5201 m), Co. Curasma (5336) etc.

This division consists mainly of Tertiary-Quaternary Volcanics. Also Jurassic-Tertiary sediments occur along the northern main deep valleys. Though the mountainous area is rich in large relief, a regional high elevation is characteristic of the entire division.

The black colored basalt lava flows are almost evenly distributed on the top portion of the high land and many leave micro-topographic features of lava flows. The advanced portion of ridges by glacial erosion shows a pinnacle view.

3-2 Eastern basin division

The eastern basin around Yauri consists mainly of (1) the Tertiary Puno Group, (2) Quaternary white tuff, (3) massive white tuff etc., and is a hilly mountainous area which is 3900-4000 m in elevation and about 100 m in topographic relief.

The main portion of this basin seems to have been formed tectonically before deposition of the sediments such as (2), (3) was overlain on the tectonic basin. The Mesozoic and Igneous rocks intruded into the Mesozoics occur as the inlier in the south-southeast part of the project area and show the projected topography from the hilly basin.

3-3 Eastern mountainous division

The eastside of the basin mentioned above: viz. northeast part of the project area, is the mountainous area where the highest elevation reaches about 5,000 m and consist mainly of Cretaceous sediments. The ridges of this division range in a NNW-SSE direction being reflected by the main tectonic line of South Peru. Because of the existence of fracture traces reflected mainly to the bedding foliations on the slope, the direction of the strike of beds can be recognized clearly. The topographic relief is very large and the ridges are generally sharp and rugged.

The photocharacteristics of each photogeological unit will be mentioned in Chapter 4.

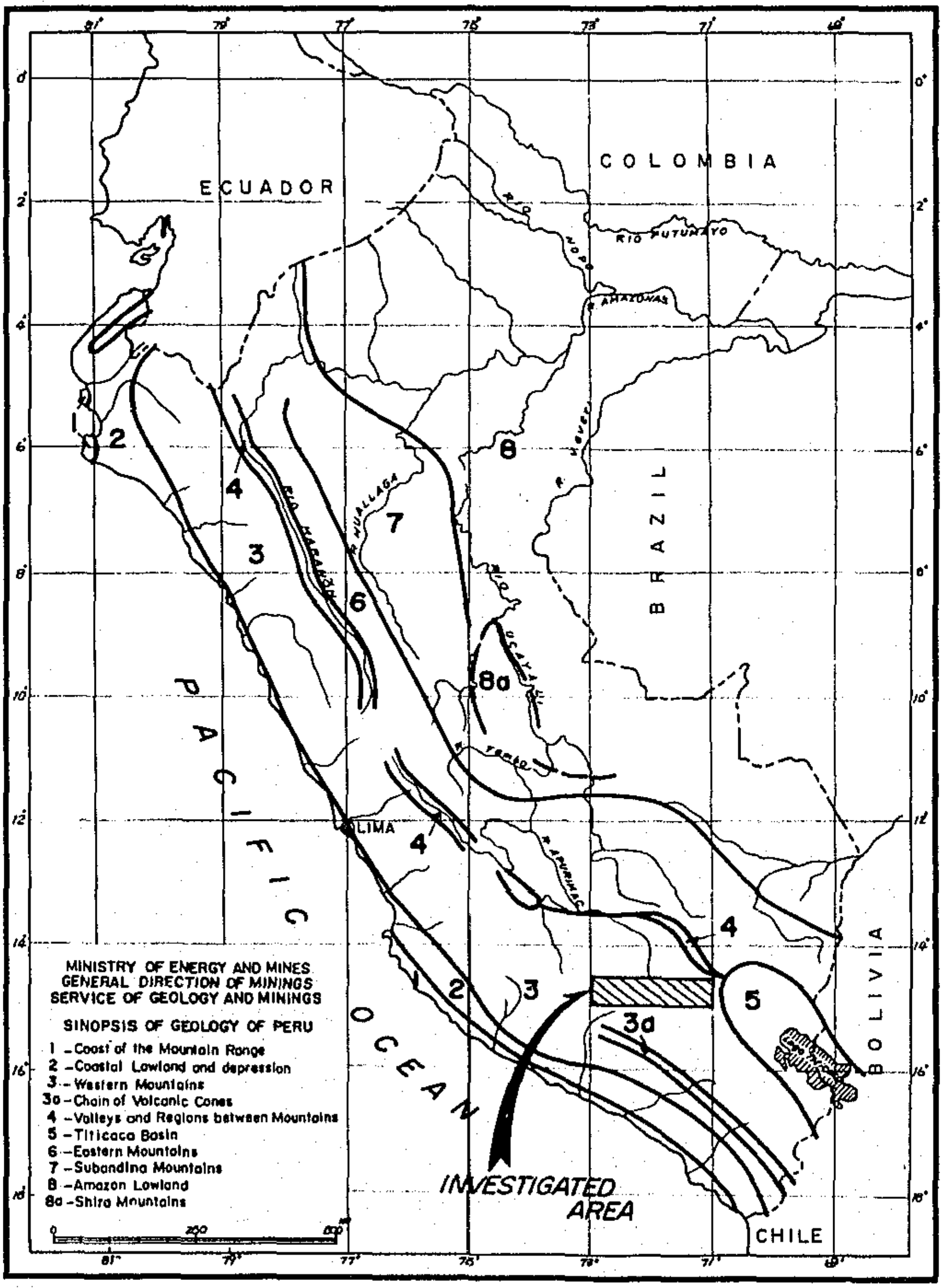


FIG.4 THE MORPHOLOGIC-STRUCTURAL DIVISION OF PERU

('SINOPSIS DE LA GEOLOGIA DEL PERU' : 1969,
REPUBLICA DEL PERU
MINISTERIO DE ENERGIA Y MINAS,
DIRECTION GENERAL DE MINERIA
SERVICIO DE GEOLOGIA Y MINERIA)

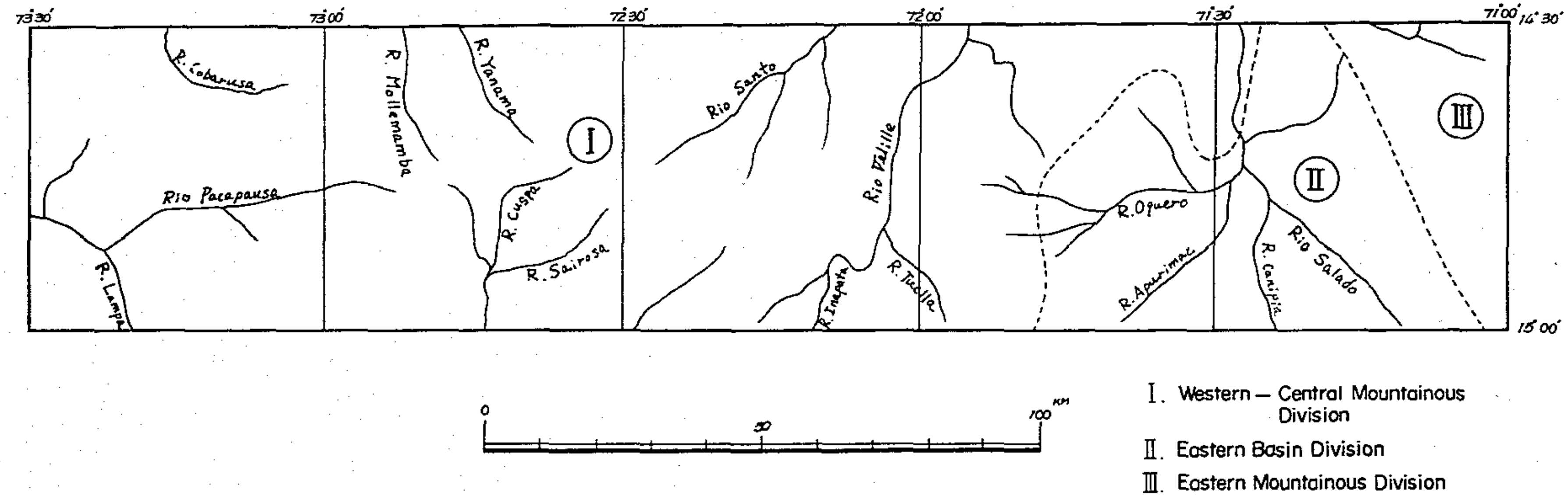


FIG.5 TOPOGRAPHIC DIVISION OF PROJECT AREA

4. GENERAL GEOLOGY

4-1 Photogeological Distribution

1) The project area is divided roughly into two photogeological divisions; viz. eastern basin and the mountainous area consisting mainly of sedimentary rocks and the high elevation area formed mainly by volcanics. The geological structures are controlled by the characteristic tectonics trending NNW-SSE all over Peru.

2) The sedimentary area of the eastern project area consists of (1) the quartzite (Yura F.) and the limestone (Ferrobamba F.) of lower-middle Cretaceous, (2) alternation of red sandstone and shale of upper Cretaceous (Capas Rojas F.), (3) volcanics, volcanic conglomerates, sandstone and siltstone of lower Tertiary (Puno Group), (4) Quaternary sedimentary rocks such as tuff, tuffaceous sandstone and conglomerate (Barroso Group), and (5) granitic rocks intruded into (1) and (2) mentioned above.

   In this group, (1) are marine sediments and occur as the roof-pendant mass on the granitic rocks. The sediments (2)-(4) are continentals consisted mainly of volcanic sediments and show zonal distributions trending NNW-SSE.

3) In the central-western project area granitic rocks occur as the basement rocks, and Tertiary volcanics (consisted mainly of tuff-tuff breccia of andesite, basalt etc.), and Quaternary volcanics (consisted of the lava flows, tuff and tuff breccia of dacite and basalt, lava flows of the dacite and andesite, dacitic tuff-tuff breccia, lava flows and tuff breccia of the dacite, andesite and basalt—Barroso Group) are overlain on the basement rocks. Besides Glacial deposits, Fluvio-glacial deposits and Fluvial deposits cover them. Also upper Jurrassic—lower Cretaceous sedimentary rocks such as black shale and sandstone of the Yura formation occur in a narrow area in the northern valleys.

4) In the Quaternary volcanics of the Barroso Group, the thick bed, consisting of white-light grey dacite tuff-tuff breccia etc., is distributed widely over the entire project area and is very effective as a key-bed for classification of the volcanics in this area. It appears possible that the Quaternary sediments consisting mainly of the white tuff-tuffaceous sandstone in the eastern project area are secondary sediments of tuff-tuff breccia mentioned above.

4-2 Geological Structure

1) The geological structures in the project area are mainly controlled by the remarkable tectonics all over Peru trending in the NNW-SSE direction.

2) In the eastern sedimentary rock area, though the unconformable relation can be seen in several places, the contact relation by faults shows that a NNW-SSE trend is dominant in most of the contact area between Tertiary volcanic sediments of the Puno Group and the white tuff-tuffaceous sandstone of the Barroso Group.

And also the alternation of red sandstone and shale of the Capas Rojas Formation contacts with the Puno Group by faults showing the same trends. Also in the other main faults, the parallel or conjugate trends mentioned above are predominant. Most of these faults show the western thrown side according to the geological distribution.

3) The fold axes in the Yura Formation and Ferrobamba Formation trend N-S, and one in the Capas Rojas of the upper Cretaceous trend WNW-ESE predominantly. On the other hand, the fold axes in the Puno Group and the Barroso Group predominantly trend NNW-SSE trending parallel to the tectonic line of this area. Namely, there is a characteristic difference in the trending of the fold axes depending on the geological age of the sediments.

4) Also in the volcanics area, middle-western part of the project area, the geological structure, mainly distribution of faults, is predominant in the NNW-SSE trend. But, few faults are generally shown in this area.

5) However, the distribution of the craters of the recent basalt flows which overlie on the top of this area trend in the NNW-SSE direction and is obviously reflected to the geological structure in this area.

6) Generally speaking, Mesozoic-Tertiary sedimentary rocks show the steep dip in bedding but the Tertiary volcanics and Quaternary sedimentary rocks show a remarkably low or horizontal dip.

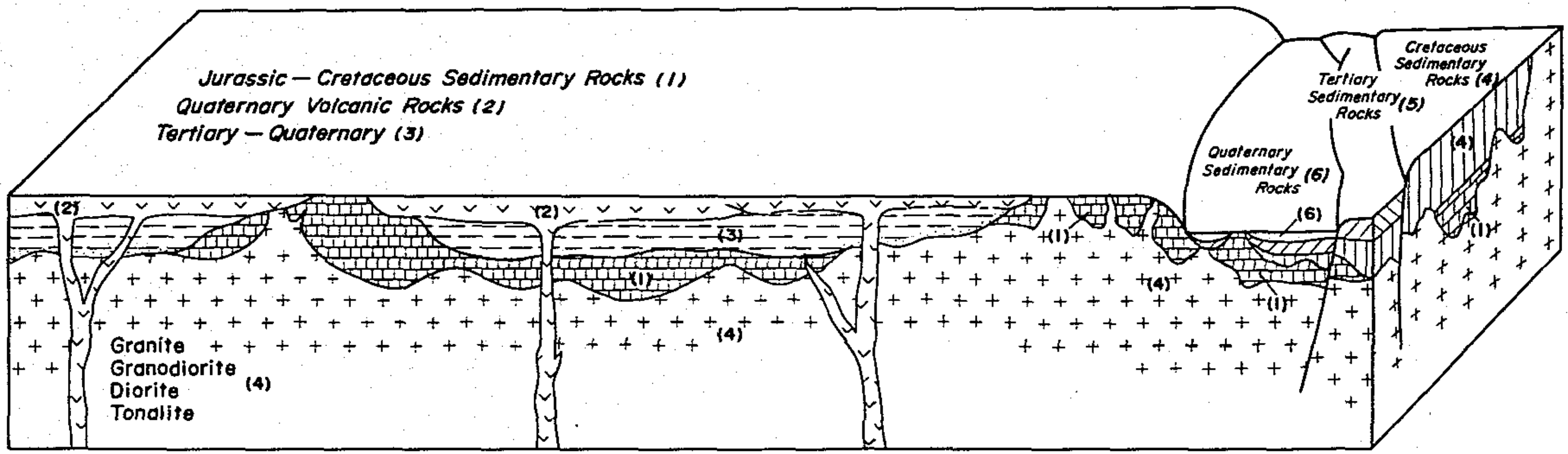
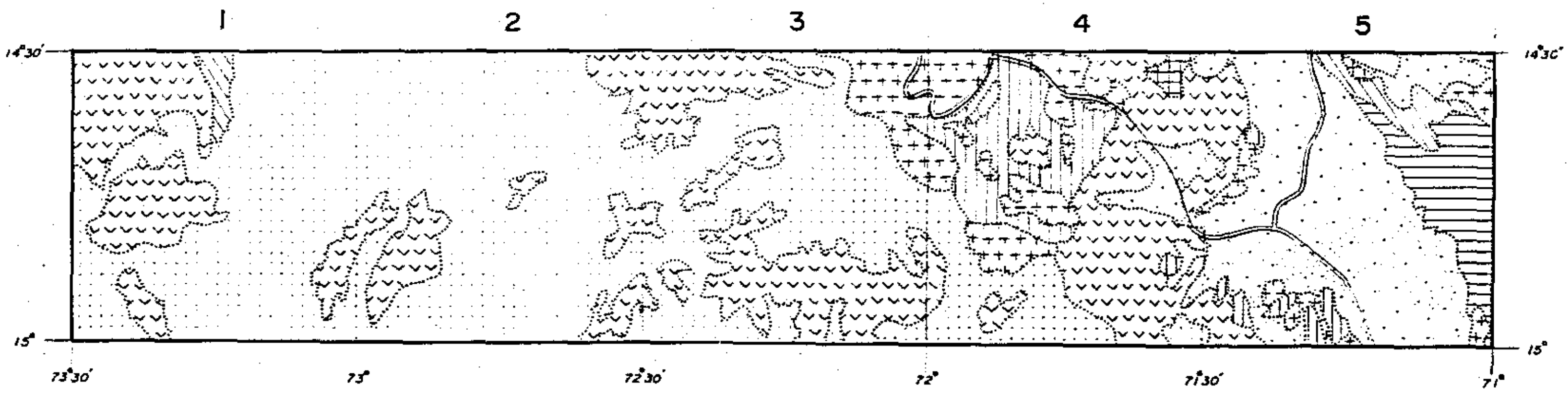


Fig.6 SCHEMATIC REPRESENTATION OF INVESTIGATED AREA



REGEND

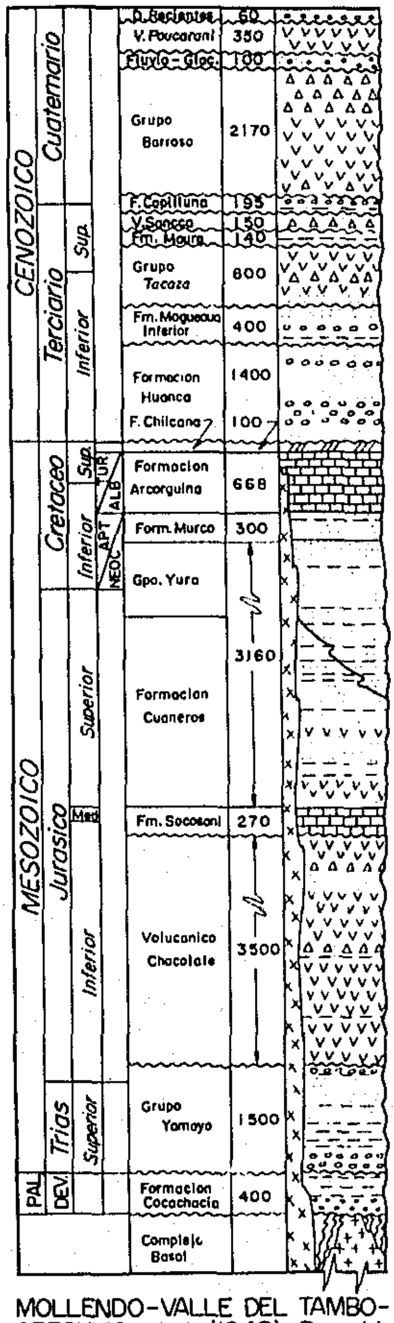
ERA	SYSTEM	FORMATIONS ※		INTRUSIVE ROCKS	
Cenozoic	Quaternary	Alluvial Deposits, Volcanic Ashes, Fluvial Deposits, Fluvio-Glacial Deposits,			
	Tertiary Quaternary Volcanics	Barroso, Capillune, Chachani, Maure, Sencca, Upper Volcanic Series,			
	Tertiary Continental and/or Upper Cretaceous	Huanca, Moquegua, Puno,			
	Tertiary and/or Cretaceous Volcanics	Tacaza,			Granodiorites Granites - Diorites Andesites - Dacites
Mesozoic	Cretaceous	Arcurquina, Ayabacas, Huancane, Moho, Muni, Muñani Murco, Sipin, Vilquechico,			
	Jurassic	Chocolate, Guaneros, Socosani, Yura,			
Paleozoic	Upper Paleozoic	Cocachacra,			

※ The formation names concerned with investigated area are extracted in this table.

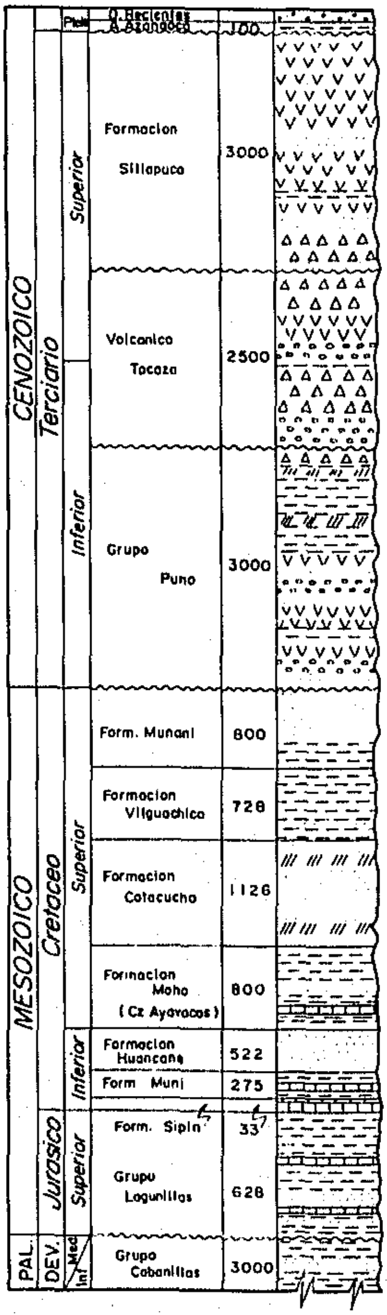
Fig.7 GEOLOGICAL MAP OF PROJECT AREA

SCALE 1 : 1,000,000

(SERVICIO NATIONAL DE GEOLOGIA Y MINERIA : 1969)



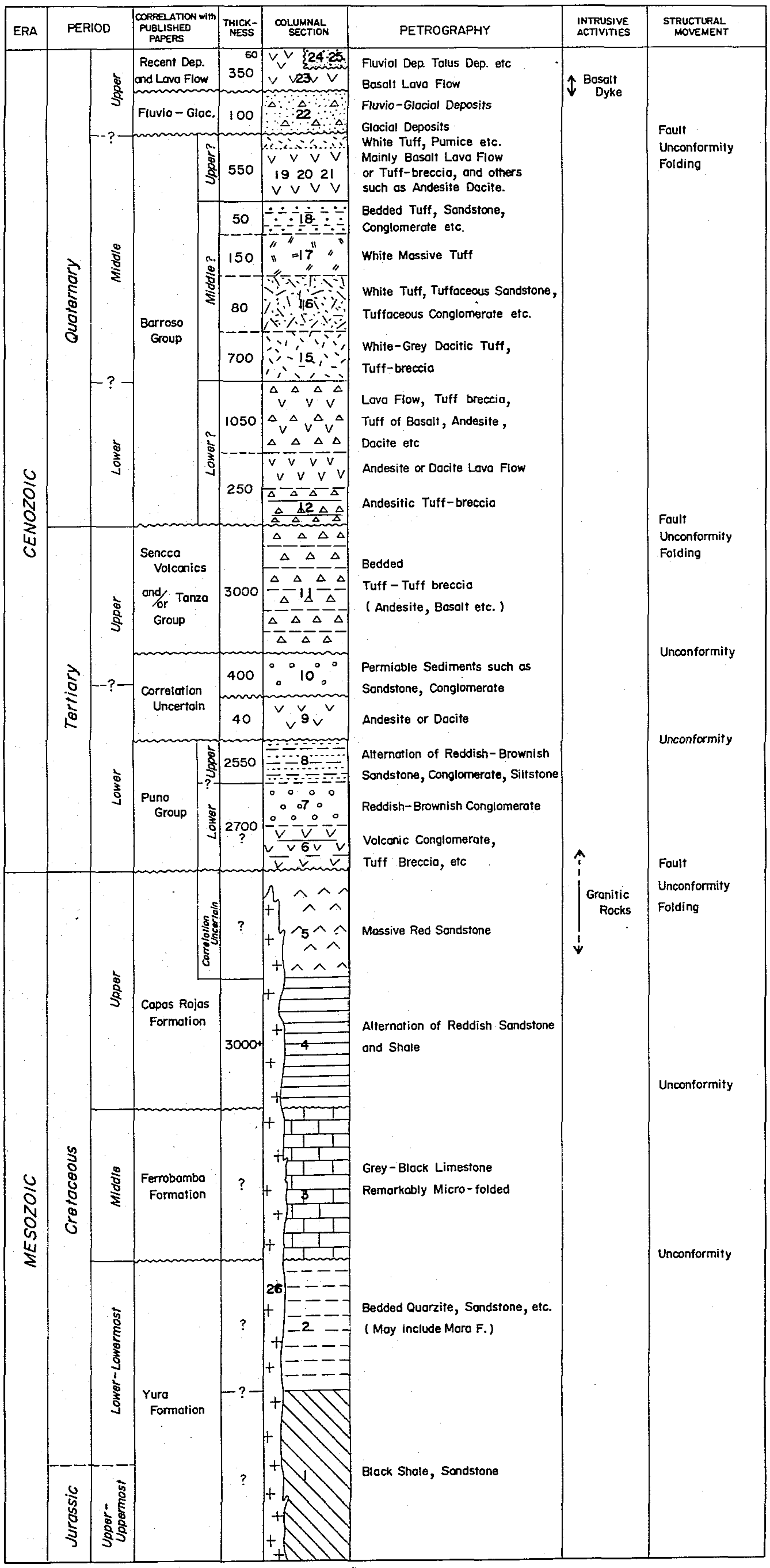
MOLLENDO-VALLE DEL TAMBO-AREQUIPA Jenks(1948), Benavides (1962), Bellido y Guevara(1963), Guevara(inedito), Vargos(inedito)



CUENCA DEL TITICACA Newell(1948), Emp Pet Fiscal(1969)

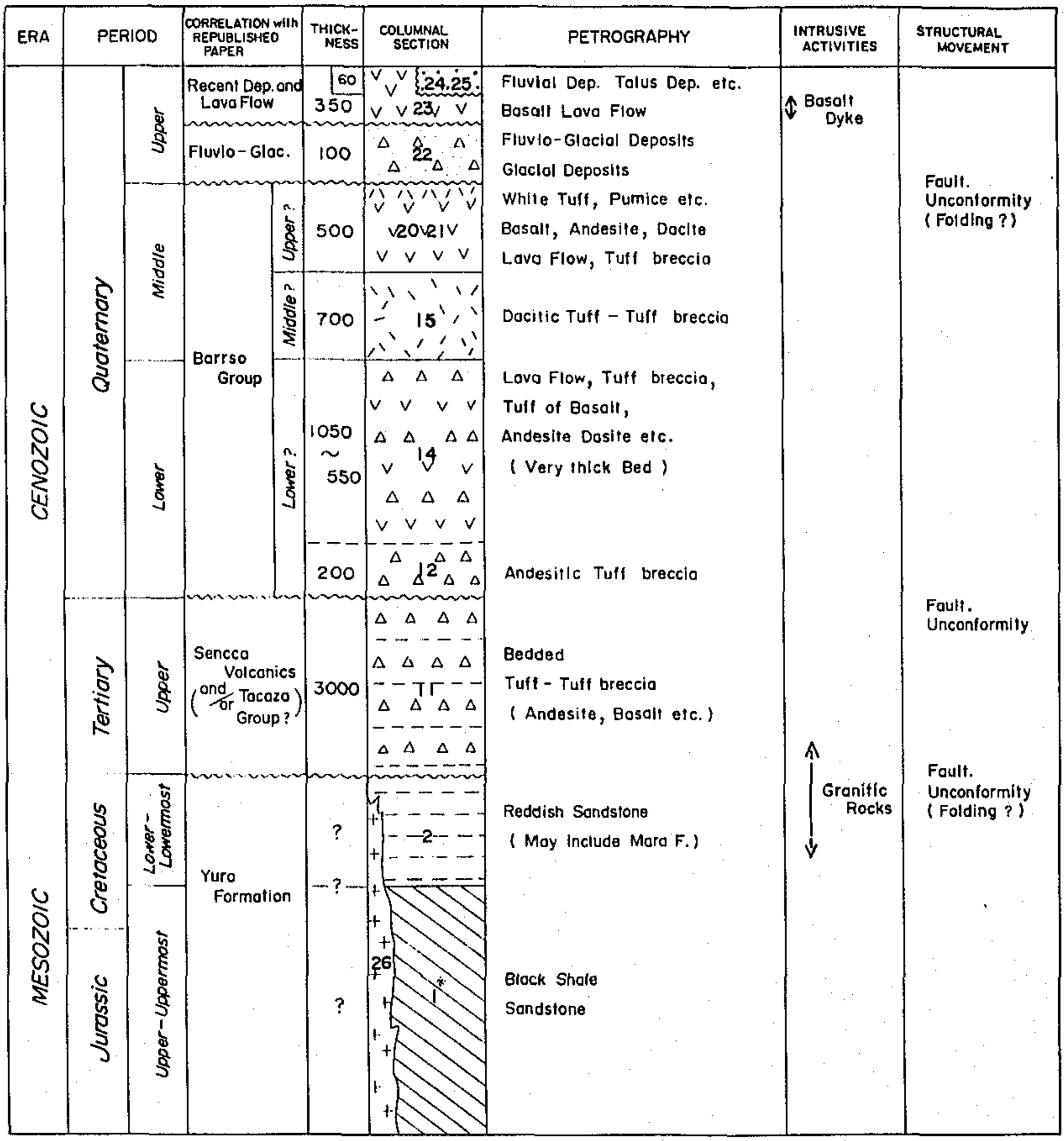
Fig.8 GENERALIZED COLUMNAL SECTIONS OF SOUTHERN PART OF PERU

("SINOPSIS DE LA GEOLOGIA DEL PERU", BOLETIN NO.22, 1969 REPUBLICA DEL PERU, MINISTERIO DE ENERGIA Y MINAS)



*Numbes correspond to one of photogeolozical maps.

Fig.9 SCHEMATIC STRATIGRAPHICAL COLUMNAR SECTION OF INVESTIGATED AREA



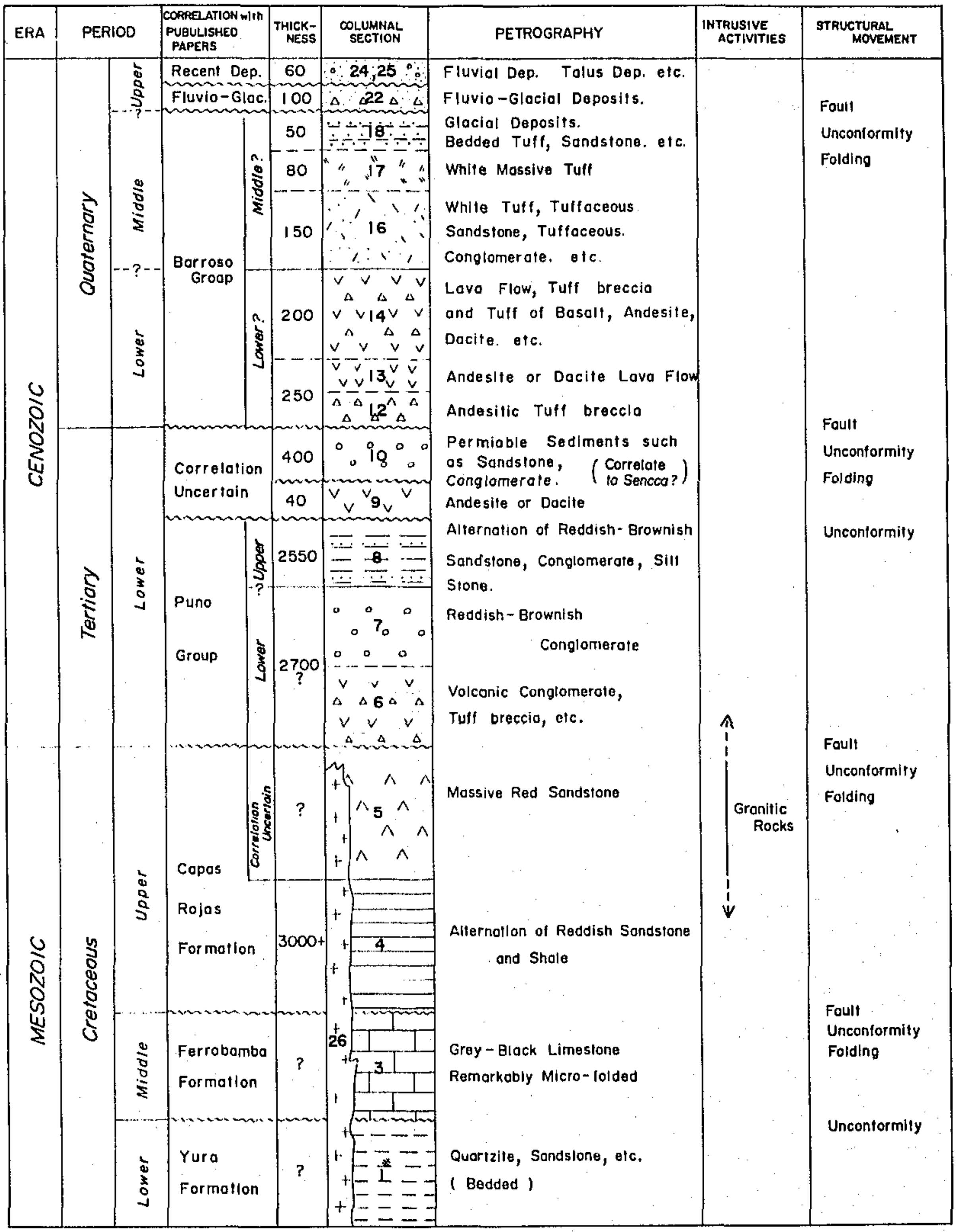
*Numbers correspond to one of photogeological maps.

Fig.10 GENERALIZED COLUMNAR SECTION OF SHEET NO.1 – NO.3

ERA	PERIOD			CORRELATION with REPUBULISHED PAPER	THICKNESS	COLUMNAL SECTION	PETROGRAPHY	INTRUSIVE ACTIVITIES	STRUCTURAL MOVEMENTS
CENOZOIC	Quaternary	Upper		Recent Dep. and Lava Flow	60	24 25	Fluvial Dep. Talus Dep. etc.	Basalt Dyke	
					350	23	Basalt Lava Flow		
				Fluvio-Glac.	100	22	Fluvio-Glacial Deposits Glacial Deposits		Fault Unconformity
		Middle	Upper ?	Barroso Group	550	19 20 21	White Tuff, pumice etc. Basalt, Andesite, Dacite, Lava Flow, Tuff breccia		
			Middle ?		100	17	White Massive Tuff		
					50	16	White Tuff, Tuffaceous Sandstone, Tuffaceous Conglomerate		
					200	15	White-Grey Dacitic Tuff, Tuff breccia		
		Lower	Lower ?		550	14	Lava Flow, Tuff breccia and Tuff of Basalt, Andesite Dacite etc.		
					400	13 12	Andesite or Dacite Lava Flow Andesitic Tuff breccia		Fault Unconformity
	Tertiary	Upper		Sencca Volcanics (and ~~or~~ Tacaza Group)	3000	11	Beded Tuff breccia (Andesite, Basalt etc ?)		Fault Unconformity (Folding ?)
MESOZOIC	Cretaceous	Middle		Ferrobamba Formation	?	3	Grey-Black Limestone	Granitic Rocks	Unconformity
		Lower-Lowermost		Yura Formation	?	26 2	Quartzite, Sandstone (May include Mara F.)		

* Numbers corrspond to one of photogeological maps.

Fig.11 GENERALIZED COLUMNAR SECTION OF SHEET NO.4



※Numbers correspond to one of photogeological maps.

Fig.12 GENERALIZED COLUMNAR SECTION OF SHEET NO.5

5. PHOTOGEOLOGICAL UNITS

5-1 Unit 1 (Black shale and Sandstone of Yura Formation)

1) This unit is only locally visible in two parts of the area: viz. (1) in the north-western valleys of sheet No. 2 and (2) in the north-western part of the project area.

   In the former area this unit is found along the valley covered by unit 11. In the latter area, it is covered by the thick bed of unit 15, whity-greyish tuff or tuff breccia.

2) On the airphotographs this unit shows a dark grey-black surface. From the fine-scaled and sharp-edged irregular surface of the slope, it is suggested that many fractures originated since joints or bedding foliations are well developed.

   Moreover, the (2) area stratifications, trending NE-SW in strike and inclining 70° toward the SE, are remarkably recognized.

   Inferring these photocharacteristics, it may be estimated that part of this unit is composed of marine sediments like black shales and/or sandstones and that these are lower members than unit 2 in age.

5-2 Unit 2 (Bedded Quartzite and Sandstone, etc. of Yura Formation)

1) This unit is found in the following area; (1) the area between Rio Canipia and Rio Salado of the southeastern part of the project area (southwestern part of sheet No. 5), (2) the vicinity of Velille (sheet No. 4), and narrowly in the northwestern area of sheet No. 2.

   In the first area (1), this unit is distributed in a NNW-SSE trending direction, which is about 3 km in width and 14 km in length. This unit is also divided into two separated areas; roughly the western and the eastern area.

   In the western area, being larger in distribution, the width is about 1.8 km in the most southern end but 3.3 km on the northern side. This is bounded by a fault on the north rim by the granitic complex of unit 26 and by a fault or unconformably on the westside by the limestone of unit 3. Moreover, this contacts in fault with the granitic complex or limestones on the east.

   The eastern small body occurs on the left side of Rio Salado which is 2 km in width and 4.7 km in length trending in a NW-SE direction. On the west this is bounded unconformably by limestone and contacts to the granitic complex in fault. Further, this is overlain by unit 16 and 24 on the east.

2) In the second area (2), this unit shows about 8 km in maximum width and is unconformably covered on the south by unit 11 (well-stratified and thick tuff-tuff breccia) or unit 13 (thick bed composed of

tuff breccia, tuff lava flow etc.) and is intruded by unti 26 (granitic complex) on the east and west side of this block.

3) This unit in area (1) displays light yellowish brown colors on the photographs. Though the surface of the slope shows some relief, an indistinct linear pattern trending in the NNW-SSE direction may show that the bedding foliation can be recognized. The ridges are considerably sharp. The drainage is poorly developed. Roughly speaking, this unit seems to be weakened in unit 7 (conglomerate?) in photographic texture. There is, however, an obvious difference between them in photographic colors.

Though it is difficult to identify these rocks by photocharacters only, it has been confirmed to be quartzite or siliceous sandstone of the Yura Formation on the basis of the field investigation.

4) According to photointerpretation, the above-mentioned unit in the block (2) area, vicinity of Velille, shows a greyish tint in color and has bedding with the strike in the NNW-SSE direction and a 40-70° dip toward the NE.

These rocks also have been identified as sediments composed mainly of sandstone (Yura Formation) on the basis of the field investigations.

5) Block (3) shows reddish-reddish brown colors and bedding with the strike in the N-S direction and a 60-70° dip toward the W, and confirmed to be composed of reddish sandstone, limestone etc. by the field investigation team. The surface of the slopes are smoother than in the shale and is poor in irregularities.

6) This unit in the eastern block and eastern part of the western block.of the distribution (2) has a 40-50° dip toward the east while it has about 40° dip toward the west in the western part of the western block. This suggests that the anticlinal axis trends in the NNW-SSE direction along the ridge of this western block

In the faults overlain on unit 2, the set of the N-S trends and the W-E trends can be recognized and the later may have been constructed more recently than the latter.

7) Though the black shale patches have been found in the western block of distribution (1) by field investigations, it was impossible to identity the distribution of black shale by photointerpretation.

5-3 Unit 3 (Grey-Black Limestone of Ferrobamba Formation)

1) This unit is found mainly in three parts of the project area; viz. (1) on the left side of the Rio Canipia, (2) in the area between Rio Canipia and Rio Salado, (3) on the right side of the Rio Salado. Block (1) and (2) occur as the roof-pendant on unit 26, granitic complex. Block (3) occurs as the inlier in the Quaternary sediments though it shows same occurrence in deeper places.

2) This unit has very characteristic features photogeologically as follows. (a) The ridges are remarkably rounded. (b) The surface

is very smooth and is poor in the small irregularities. (c) It displays a dark grey-block color. (d) The rather lighter colored stripe patterns which may indicate that the bedding foliations can be recognized clearly on the dark surface. (e) The patterns mentioned above are remarkable bent and this fact may suggest the development of small-scaled folding. (f) The developments of drainage is poor. (g) This unit occurs as small chopped blocks.

According to these photocharacteristics, unit 3 is identified with limestone easily and has been confirmed to be limestone of the Ferrobamba Formation by field investigations also.

3) The folding structures in this unit can be clearly recognized depending on the lighter stripe patterns on the dark surface. And it can be understood that the folding system is very fine and complicated according to the photointerpretation.

   The trending of the folding axes is predominant in the N-S directions and is similar to the one in unit 1. This fact suggests that these foldings in unit 1 and this unit were caused by the same tectonic activities.

4) When detailed field investigations are carried out, more complicated and fine structures will be clarified.

5) The lack of sinkholes in this unit, which are characteristic in common limestone, indicates that this unit may be a considerably impure limestone, which means mudy or dolomity limestone.

5-4 Unit 4 (Alternation of the Red Sandstone and Shale of Capas Rojas Formation)

1) This unit is widely distributed in the northeastern part of the project area. The southwestern side of this unit contacts with unit 8 (alternation of reddish brown sandstone, conglomerate and siltstone of Puno Group) in clear fault and the southern side contacts with unit 6 (volcanic conglomerates and tuff breccia of Puno Group) and unit 7 (reddish brown conglomerate) etc. in the fault. Though the eastern rim of this unit viz;the boundary between unit 4 and unit 6 or unit 7 is considerably obscure, it is roughly delineated as shown on the photogeological map (sheet No. 5).

2) This unit contact with unit 5 which is estimated to be reddish massive sandstone but correlation is uncertain upstream of the Q. Soclla (sheet No. 5). The correlation between unit 4 and unit 5 is indistinct. Though unit 5 seems to have been intruded into this unit at first glance, unit 5 should not be igneous rock because slight bedding foliation is locally visible. Moreover, a clear discontinuity between unit 4 and unit 5 cannot be recognized on the photographs.

   Under these circumstances, the relationship between this unit and unit 5 seems to be contemporaneous heterotopic facies to each other.

3) This unit displays fairly dark reddish brown colors and is remarkable in the development of the bedding foliations. The development of the drainage cources is predominant in the strike parallel and in the dip direction. Though the ridges are generally sharp, it is not as sharp as in the black shale of unit 2 mentioned above.

   Considering these photocharacteristics, this unit is estimated to comprise the alternation of red sandstone and shale.

4) However, the remarkably rugged and irregular areas which are shown in the photogeological maps by the triangle hatch are very similar to unit 6 in the photographic features and seems to comprise of volcanic conglomerates or conglomerates.

5) Many faults are observed in this unit and the major fault bounded to unit 8 has a NNW-SSE trend. The other faults trend oblique on parallel to the major faults and they are generally strike parallel faults in the majority of cases.

6) In the central part of the unit, the fault zone or sheared zone trending to the NNW-SSE direction, which are shown by "FZ" in the photogeological maps, are interpreted and unit 4 is remarkably sheared in these portions.

7) In the northern part of this unit, the foldings parallel the main faults viz; a WNW-ESE trend is observed.

5-5 Unit 5 (Massive red sandstone of Capas Rojas Formation)

1) This unit is distributed in the northeastern part of the project area viz; northern side of unit 4 (sheet No. 5) approximately 10 km in width in maximum and 34 km in length. As before, this unit is estimated to be a contemporaneous heterotopic facies of unit 4. The southern side of this unit contacts in fault with unit 6, unit 7 and unit 8. And it seems that this unit contacts in strike fault tranding WNW-ESE with unit 4 in the southern rim of the western half block but gradually changes to unit 4 in the eastern half block.

2) Although the block of this unit occurs like the inlier in the western part of this unit, the clear boundary between this and unit 4 cannot be recognized. Moreover, unit 5 contacts in fault with unit 4 in the northewestern rim of this block and is unconformably overlain in the other northern rim by unit 16 (white tuff, tuffaceous sandstone etc. of Barroso Group) and glacial deposits.

3) This unit displays the bright red-reddish brown color though it partially shows a reddish purple color. Although large topographic relief is observed, the mountain sides are generally smooth. The grey-light green rocks which are ruggedly projected and seem hard are distributed discontinuously as if showing the bedding on the smooth surface of the slope. Also rather light or dark winding stripes are visible on the smooth red slopes and these seem to show bedding foliations. The ridges are rounded but less than the

limestone of unit 3 though the topographic relief is larger. Moreover, microtopography showing the bedding foliations slightly are only locally visible.

From these photocharacteristics, this unit is estimated to be massive red sandstone.

4) The southern part of this unit which displays reddish purple and has a very fine rugged surface is folded and seems to be comprised of conglomerates or volcanic conglomerates.

5-6 Unit 6 (Volcanic Conglomerates—Tuff breccia of Puno Group)
Unit 7 (Red-brown Conglomerates of Puno Group)
Unit 8 (Alternation of Red-brown Sandstone, Conglomerate, Siltstone etc.)

1) Units 6, 7 and 8 seem to be a series of a continentals with about the same age and has been overlain conformably in order of units 6, 7, 8 originally. An approximately 12 km wide belt in maximum, upstream of Rio Pallpatamayo, of the series above traverses the project area from north to south trending in a NNW-SSE direction. As each of these has bedding showing a NNW-SSE strike and a dip to the SW direction, these are inferior toward the east. Namely, unit 6 is the lowermost and unit 8 is the uppermost.

2) Unit 6 displays a brown-dark brown color, and is fine rugged and large in topographic relief. The mountain slope is generally steep and sharp. These aspects give us a very brittle feeling. The photolineations showing the bedding foliation trending NNW-SSE can be interpreted all over the distributed area of unit 6 but not as clearly as in unit 8.

From these photocharacteristics, unit 6 is considered to be composed of volcanic conglomerate-tuff breccia etc.

3) Unit 8 displays a red-reddish brown color and shows fine well-defined bedding which has a NNW-SSE trend in strike and a 40°-70° dip toward the SW direction. This unit is more compact and has stronger resistance against erosion than units 6 or 7 and is rich in the development of fine drainage. From these photocharacteristics, unit 8 is estimated to comprise the alternations of red-brown sandstone, conglomerate, siltstone etc., and is partially confirmed in the southeastern part of the area (sheet No. 5) by the field investigation team.

4) In the inferior part of this unit viz; near major faults located between unit 4 and unit 6, whitish beds which may be comprised of tuff, approximately ten meters in thickness, can be recognized.

5) Unit 7 displays intermittent characteristics than unit 6 and 8 on the airphotos. Namely, the bedding foliation in unit 7 on the photographs is clearer than in unit 6 but less clear than in unit 8.

6) Unit 7 contacts in fault on the northern part and is conformably overlain with unit 8.

7) The folding axes trending NNW-SSE are developed in the block of unit 8.

The relation between units 8 and 16 is originally unconformable and can be recognized in the northern distributed area, but now is in fault relation in the boundary area between them.

5-7 Unit 9 (Correlation Uncertain Volcanic Rocks)

1) This unit is only locally found mainly in four parts of the southeastern project area viz; (1) on the left side of Rio Jaruma where it overlies unit 8, (2) on the left side upstream of Rio Pallpatamayo where it covers unit 7, (3) on the right side of the Rio Pallpatamayo where it is on unit 8, (4) and on both sides of the tributary of Rio Challuta where it overlies unit 8 also.

2) In these areas, blocks (1) and (3) were confirmed to be comprised of dacite or andesite by the field investigation team.

3) Although more masses of this unit were confirmed by field geological investigations than by photointerpretation, only masses interpreted on the photographs are shown on the photogeological maps.

4) According to the route-maps prepared by the field geological investigation team and the results of the photointerpretation, the series of the masses composing this unit seem to be discontinuously distributed in a NNW-SSE trend which is predominant in the area, on unit 7 and unit 8.

5) The color of this unit is similar to that of unit 7 and unit 8 on the airphotos. This unit, however, does not have bedding foliations entirely as in units 7 and 8 which show clear beddings. Further, this unit has a relatively smooth surface, some drainage and flat tops.

6) It is quite obscure which is correlated to this unit in view of the many volcanic rocks in this project area. However, it is considered that unit 9 was brought about by different volcanic activities, which is estimated to occur in connection with the forming of major faults trending in the NNW-SSE direction, from other volcanic rocks which are distributed in the middle-western part of the project area, considering the structural arrangements mentioned in 4).

5-8 Unit 10 (Correlation Uncertain Sandstone, Conglomerate)

1) This unit occurs in the northeastern part of the project area; on the west side of El Desconso which is located in the left side of Rio Huacra Huacho, which is 2.5 km in maximum width and 5.5 km in maximum length.

2) This unit is similar to unit 6-8 in color displaying a reddish brown but is remarkably different from unit 6-8 because of less development of bedding foliations. Though fine parallel drainage

patterns are developed along the dip slopes, general erosion on the mountainside is poorer than in units 6-8. For this reason, the mass comprising unit 10 forms a projected topography around the terrain.

3) This unit shows a monoclinal structure with a NW-SE strike and 30 degrees dip toward the SW direction, but the bedding foliations are very obscure.

   Considering these photocharacteristics, this unit is estimated to be comprises of the permeable sediments such as sandstone or conglomerates.

4) This unit is undoubledly younger than unit 8 because the latter overlies unconformably on the later which is folded. Further, considering general elevation and photocolor, this unit is estimated to be older than adjacent unit 16 (white tuff-tuffaceous sandstone etc.). But actually, the direct contact point cannot be interpreted.

5) From these circumstances, the correlation of this unit with published maps is quite obscure.

5-9 Unit 11 (Sencca Volcanics and/or Tuff breccia of Tacaza Group)

1) This unit occurs in the valleys of the following area; (1) Rio Velille basin and Rio Santo basin near longitude 72° west, (2) left side of Rio Yanama, (3) vicinity of Chumpayo Lomas, (4) the area between Rio Ynahuarako and Rio Mollebamba, (5) Rio Pacapausa basin, (6) the portion between Rio Jaculta and Rio Colcahambe.

2) This unit displays a greyish brown-dark brown color, seems to be more compact than other tuff breccias and shows slight bedding occasionally. Moreover, this unit has a very fine rugged surface which is a characteristic features lacking in the other units and appears to be due to the differential erosion on the slopes. Further, sometimes the areas of unit 11 are utilized for orchards, vegetable gardens or residential lands.

   Considering these photocharacteristics, this unit may comprise the tuff breccia-tuff of Sencca Volcanics and/or Tacaza Group.

3) Midstream of Rio Velille, this unit shows a NW-SE trend in strike and a 10°-40° dip toward the SW direction. Assuming 20° in average dip of bedding, the thickness of this unit in block (1) above is calculated to be 3000 m approximately. Though the bedding foliations are obscure in the Rio Pacapausa basin, the thickness of unit 11 is more than 1,100 m assuming the horizontal bedding. Thus, unit 11 forms very thick beds all over the area.

4) A part of this unit is confirmed to be comprised of the alternation of volcanic breccia-tuff breccia and sandy tuff in the Rio Velille by field investigations.

5) In block (1) above, unit 26 (granitic rocks) locally occurs as the inlier mass in this unit.

5-10 Unit 12 (Andesitic Tuff breccia of Lower Barroso Formation)
Unit 13 (Andesitic and Dacitic Lava Flow of Lower Barroso Formation)

1) The photogeological units underposed unit 15, mentioned later, and superposed unit 11 are divided into three units; unit 12, unit 13 and unit 14 in ascending order. Unit 12, the lowermost among them, is distributed in the following area and overlies unit 26 (granitic rocks); (1) the left side of Rio Apurimac in Yauri district, (2) the right side of Rio Oquero, (3) both sides of Rio Sanu, (4) both sides of Rio Apurimac and (5) the upper stream of Rio Huayllmayo in the southern Yauri area.

2) Unit 12 displays a dark brown-greyish brown color, and is somewhat similar to unit 11 in color. However, this unit seems looser in texture than 11, moreover, it is the most characteristic that the bedding foliations are clearly distinguished on the airphotos. Based on these photocharacteristics, the following facts may be interpreted easily; this unit inclines toward the northwest about 20 degrees in the (1) area, toward the south about 10 degrees in the (5) area and is horizontal in the others. Though there is little characteristic in the drainage patterns, roughly speaking, "dendritic" patterns are often recognized. The ridges are not as sharp but form a "Step" shaped topography in places because of the well-developed bedding.

3) It is inferred that unit 13 is comprised of andesitic or basaltic lava. Though this unit covers unit 12, the volcanic activities may be justly estimated to be at about the same time as unit 12. For this reason, it may be better to consider that unit 13 is a part of unit 12. The superposed relationship between unit 13 and unit 14 is uncertain.

5-11 Unit 14 (Lava Flow of Basalt, Andesite and Dacite, Tuff breccia and Tuff of Barroso Formation)

1) This unit is widely distributed all over the west of the Yauri area and overlain by unit 15 (white-whity grey dacitic tuff and tuff breccia). On the right side of Rio Oquero, the left side of Rio Sanu and Rio Jaromajo in the eastern part of the project area, this unit covers widely unit 12. Then in the central and western part of the project area this unit overlies on unit 11 distributed in major deep valleys.

2) In the eastern part of the project area (sheet No. 4 and No. 5), glacial erosion does not progress, and debris formed on the slopes of the mountain side are easily transported to the rivers. Accordingly, in order that unit 15 does not remain upon slopes composed of unit 14, this unit is never mistakenly interpreted. On the contrary, in the central-western part of the project area, photointerpretations are frequently confused because of erosional debris of unit 15 overlied on this unit.

3) This unit displays various colors; the deep-black portion (seems to be baslat), the reddish-brown portion (may be comprised of andesitic or basaltic rocks), and the light tone portion which is greyish white-greenish grey (seems to be composed of dacitic rocks or altered volcanic rocks). As these rocks interact in complex with each other, it is very difficult to divide these rocks only by means of photointerpretation. In this study, it is considered that these patterns are lumped into unit 14 and this unit may be correlated to the lower Barroso Group.

4) This unit is a very thick bed because many types of lava, tuff breccia and tuff interact in complex. Generally speaking, this unit is thicker in the western part of the project area and tends to decrease in thickness in the eastern part. Namely, this unit is more than 1050 m in maximum thickness in the western part (for instance 1050 m in Rio Pallancata area and 900 m in Rio Pisquiccocha), but in the eastern part (sheet No. 4) is only 550 m in maximum thickness (for instance in Rio Callarayoj valley).

5-12 Unit 15 (White-Grey Tuff-Tuff breccia of Barroso Group)

1) This unit is widely distributed from east to west in the project area overlying unit 14. Moreover, because of the easy and distinct interpretation, this unit is very effective as a key bed for division of volcanics in the area. Unit 12 originally overlies unit 14 in all areas, but recently it is found mainly around the area overlain by the basalt lavas.

2) This unit is characteristically white-pale yellowish grey, has a rather rounded ridge and appears to be comprised of very fine elements. From these photocharacteristics, this unit is estimated to be consisted mainly of dacitic tuff, may partially include the tuff breccia beds. The dacitic tuff observed by the field investigation team in some places may be a part of this unit.

3) This unit does not have the uni-color in all the area. Namely, it partially displays a grey-dark grey or black color like in basalt. This may suggest that this unit is consisted of not only dacitic tuff but also other volcanic materials such as tuff breccia or scoria of andesite or basalt.

4) The bed comprising this unit is relatively thick and the thickness increases toward the west. Namely, it is 700 m in maximum thickness in Rio Jacultamayoc basin of the western project area but 200 m in the Rio Apurimac basin.

5) Sometimes this unit or the secondary sediments are distributed in the bottom of the valleys also (See sheet No. 2).

6) This unit is erosionable, moreover, the debris derived from this unit by the erosion is overlain on unit 14 in the western-middle part of the project area.

5-13 Unit 16 (White Tuff-Tuffaceous Sandstone of Middle Barroso Group)

1) This unit is widely distributed in the western area; both sides of Rio Oquero and Rio Jaro Mayo to the mass of unit 8 in the eastern part of the project area.

2) In the eastern distributed area, this unit is considered to contact mainly in fault with unit 8 but is considered reasonable to be in unconformable relation in the northern boundary for about 10 km. Also outside of the fault bounded by both units viz; mainly upstream of Rio Cayrahuire, this unit distinctly overlies on unit 8 unconformably.

In the western project area, this unit overlies unconformably on the granitic rocks of unit 26 in the Rio Collpamayo basin or on the left side of Rio Salado and on the andesitic tuff breccia of unit 12 upstream of Rio Collpamayo, both sides of Rio Oquero, and both sides of Rio Jaro Mayo. On the other hand, it is covered with unit 17 (Massive white tuff), unit 18 (bedded tuff, sandstone, conglomerate etc.), and unit 24 (Terrace deposits).

3) Because of the characteristic white color, this unit cannot be confused with other unit. Especially, the cliff facing the stream shows a fresh and bright white color. This unit forms a hilly terrain which shows very fine relief and has a very close "dendritic" drainage pattern. These topographic features may suggest that this unit is composed of very fine and homogeneous sediments all over the distributed area. Namely, this unit may be correlated to the white tuff-tuffaceous sand of the middle Barroso Group.

4) As mentioned above this unit forms a hilly terrain with 100-150 m of relief, thickness of bed is estimated to reach about 150 m or more. Possibly, this unit may be a neritic sediments which is derived from unit 15 above and deposited in the shallow sea.

5) The faults observed on this unit are few but only locally visible near major faults.

6) In the distributed area of this unit, especially in the northern half, the folding structure is developed and has an anticlinal or synclinal axes trending in the NNW-SSE direction 2-17 km in length approximately.

As these axes appear to be cut by faults in some places, it is considered that the folding activity occurred before a major fault movement in this unit.

5-14 Unit 17 (Massive White Tuff)

1) This unit is found in (1) Rio Huayllumayo basin and (2) Rio Aprimac basin of the eastern project area. In block (1), this unit is about 10 km in maximum length, overlies on unit 3, unit 12 and unit 26, and is overlain at the northern margin with unit 18. In the block (2), this unit is about 9 km in maximum width and about 25 km in length and is overlain with unit 18 and unit 24 (Terrace dep.) at the northeastern margin. Further, in block (2), the distribution of this unit extends toward the south of the project area.

2) This unit displays a characteristic white color with brownish black spots like sand and seems homogeneous in the whale mass. The surface of these masses is very flat but the cliffs alongside the streams are steep and nearly vertical. Further, because of the differential erosion, the boundary between unit 17 and the other units is clearly visible.

From these photocharacteristics, this unit may suggest of being white and homogeneous but rather brittle volcanics; viz. massive white tuff which may partially include pumice flow.

3) This unit is about 80 m in thickness in block (1) and about 100 m thick in block (2).

They appear to have horizontal bedding on the photographs, but actually may incline downstream by about 3 degrees.

4) A part of this unit is confirmed by the field investigation team to be massive white tuff midstream of Rio Apurimac.

5-15 Unit 18 (Bedded White tuff, Sandstone and Conglomerate of Middle Barroso Group)

1) This unit is locally distributed on both sides of (1) Rio Salado, (2) Rio Canipia and (3) Rio Huayllumayo.

2) Unit 18 overlies on unit 3 (limestone) and unit 16 (white tuff) unconformably in block (1) and overlies on unit 3, unit 12, unit 16 and unit 26 unconformably and is overlain with unit 24 in block (2). Further, this overlies on unit 3, unit 16, unit 17 and unit 26. Then, this unit is more superior than unit 17.

3) This unit is similar to unit 16 in the rock facies containing white tuff but different from in the remarkable bedding foliation.

Namely, the stripes composed of white materials, dark brown materials or yellowish materials are visible on the airphotos. Generally this unit overlies horizontally but slightly inclines toward a dipping shape on the left side of Rio Canipia.

These photocharacteristics may suggest that this unit is consisted of alternation of white tuff, sandstone, conglomerate etc.

5-16 Unit 19 (Andesitic or Dacitic Tuff breccia of the upper Barroso Group)
Unit 20, 21 (Andsitic, Dacitic and Basaltic Lava or Tuff breccia of the upper Barroso Group)

1) In this study, photogeological units, all are volcanics, situated between the white tuff of unit 15 mentioned above and the uppermost basaltic lava flow. They are stratigraphically and in large category divided into three units. The lowermost unit is inferred to be dacitic tuff breccia, and the middle and lower units are inferred to be andesitic, dacitic and basaltic lava flow or tuff breccia. As unit 20 is able to be actually finely divided into three sub-units in some areas, these are considered as three subunits on the photogeological maps.

2) Unit 19 is distributed in the following area covering the white dacitic tuff (unit 15); on the left side of the Rio Toquepala (sheet No. 4), the branches of the Rio Oquero and the upstream area of the Rio Altaccacca (sheet No. 4), etc. This unit is covered by unit 20 and 21. On the surface of this unit, namely near the boundary of unit 21, a thin bed composed of white and fine materials as white tuff are intermittently distributed.

3) Unit 20 is divided moreover into three sub-units on the right side of the Rio Oquero as mentioned above, but on the left mountain side of this river it is difficult to divide it into the same sub-units. A part of this unit is confirmed by the field investigation team to be grey andesite on the route from Copaque to Velille.

4) Unit 21 is distributed covering unit 19, 20 and 15 and is consisted of volcanics typified mainly by tuff breccia and it appears that this unit is partly consisted of lava flow. The flat topographic surface is often formed in mainly the higher lands where the unit 21 is distributed.

5) Upstream of the Rio Oquero, the lower strata than the unit 20 is cut at the fault elongating in the NNE-SSW direction and inclined toward the east. Due to this fact, unit 15, which overlies in fairly higher land at the western side of this fault, is found in lower land such as the banks of the Rio Cangalle and Rio Arenas (branch of the Rio Oquero) at the eastern side.

5-17 Unit 22 (Glacial Deposits and Fluvio-Glacial Deposits)

1) All over the project area, glacial deposits, consisting mainly of glacial moraine and fluvio-glacial deposits which are formed by glacial erosion are found in narrow distribution.

2) These sediments connected with glaciation appear as dull medium brown-dark greyish brown on the photographs and have a very smooth surface and soft aspects, which sometimes causes confusion with tuff deposits on the mountain side or with terrace deposits on the flat plains.

3) This unit is mainly distributed widely in the following areas; (1) the upstream area of the Rio Payacchuma of the northeastern project area (sheet No. 5), (2) both sides of Rio Challuta (sheet No. 5) and (3) the left side of Rio Jaro Mayo.

4) In these occurences, block (1) consists mainly of lateral moraine and block (3) consists of medial moraine 2 km in width and 10 km in length. And block (2) is undoubtedly consists of fluvio-glacial deposits and forms a terrace-like terrain.

5) Many small scaled moraines about 2 km in length and 300 in width are distributed in the areas where glacial cirques are found.

6) Further, many characteristic glacial terrains such as large scaled glacial striaes, glacial lakes, glacial steps etc. are scarred on the bottoms extending from glacial cirques or peaks.

5-18 Unit 23 (Black Basalt Flow)

1) This unit is mainly distributed discontinuously in the mountainous area of the middle-western project area and overlies on unit 14 or 15.

2) This unit is divided roughly into three members: viz. (1) the mass overlain by tuffaceous materials which display a light grey-yellowish light grey color. (2) considerably eroded mass without tuffaceous materials on the surface. (3) fresh and non-eroded mass without tuffaceous materials on the surface.

   In these divisions, member (3) may possibly include the products of historial volcanic activity which flowed into the young valleys and covered the river bed deposits. In the eary period of basaltic volcanic activity (2), it is estimated that the eruptions of ash or pumiceous materials occurred and formed the tuffaceous materials in member (1).

3) The three divisions, however, are not shown on the photogeological maps. The flow structures are clearly visible in each member (1)-(3).

4) Because of a black-dark brown color and a tendency toward flat terrain, this unit seems to have low viscosity. Namely, this unit is estimated to be basaltic lava flows.

5) The clear craters of these basaltic flow trend in an NNW-SSE direction. This fact is very concordant to the trend of the major geotectonic structure.

5-19 Unit 24 (Terrace Deposits, Talus Deposits, Fan Deposits)

1) This unit is mainly distributed in the following five areas; viz. (1) left side of Rio Oquero, (2) Rio Apurimac basin, (3) right side of Rio Huayllumayo, (4) Rio Canipia basin and (5) Rio Salado basin.

2) Most of the terrace deposits of the area seem to be so called "erosional terraces." Therefore, the thickness of sediments is very thin and sometimes the basal rocks of the terrace are exposed as in the Yauri territory.

3) Only a large distribution of talus is shown on the photogeological maps.

5-20 Unit 25 (Alluvial Deposits)

1) The most young sediments along the recent streams were shown as unit 25.

2) This unit is mainly distributed widely in the following basins; viz. Rio Salado, Rio Canipia, Rio Apurimac, Rio Oquero, moreover, distributed in many other narrow areas.

3) This unit is composed of not only one plane but also two or three plans. They, however, cannot be expressed as terrace deposits because of their local distribution.

5-21 Unit 26 (Granitic Rocks)

1) This unit is distributed in the following areas;

   (1) the northeastern part of the project area, where situated in the northeast corner of sheet No. 5,

   (2) the basin of Rio Salado, Rio Canipia and Rio Oquero and

   (3) the basin of Rio Chillorolla and the southern vicinity of Velille.

2) In block (1) above, this unit is larger in the extension toward the east, therefore, the western edge of the unit is only recognized in the project area.

3) This unit, in block (2), includes unit 1 (chert, siliceous sandstone etc.) and unit 3 (limestone) as the roof-pendant, and partiary contacts with them. Further, this is covered unconformably with unit 12 (andesitic tuff breccia), unit 16 (white tuff) and unit 17 (Massive white tuff).

It is considered to contact in fault with unit 12, unit 14 and unit 16 on the western side of Coporaque, and this unit is also located in the tops of mountains. Then on the left side of the Rio Oquero, it appears that this unit should be included with unit 12. But actually there is no intrusive relations between them, and unit 12 overflowed and was buried. Namely, unit 26 occurs as the inlier at this place.

4) In block (3), this unit intrudes into the unit 2 (black shale, sandstone etc.) and is overlain by unit 11 (tuff-tuff breccia), unit 12 (andesitic tuff breccia) and unit 14 (lava flows of andesite, dacite and basalt, tuff breccia, tuff). Also in this area, unit 26 occurs as the inlier as well as in block (2).

5) This unit displays a pale bluish-grey to pale greenish-grey color on the airphotos, and many photolineations originated and probably joints are remarkably recognized in block (3).

   It seems that the mountain slopes are relatively smooth in surface texture and composed of very hard rock. Unit 26 in block (3) is extended toward the north area of the project area and shows a fine "dendritic" pattern of drainage. From the photocharacteristics above, this unit is concluded to be granitic rocks.

6) In some parts of block (2), this unit was partially classified as diorites and granodiorites by the field investigation team, moreover, in some parts of block (3), granites. However, differences among these rocks cannot be distinguished by photointerpretation.

5-22 Unit 27 (Basalt Dyke)

1) In the eastern part of the project area, a few dykes are locally visible and are emphasized as unit 27.

2) Inferring to be black-blackish brown in color and to intrude into units 14 and 15, this unit seems to be the basalt dyke.

6. PHOTOGEOLOGICAL STRUCTURE

6-1 General Structure

Since the linear patterns interpreted on the photographs cannot be confirmed by field investigation, we should classify them in accordance with Lattman's definition (1958). Namely;

1) the continuous (more than 1 mile in length) linear patterns which seem to be a fault or sheared zone are called "Photolineaments"

2) the noncontinuous (less than 1 mile) linear patterns that reflect the bedding foliation, schistosity or joint, are called "Fracture Traces"

However, in the first definition, the usual term "Fault" (restrictively speaking, the term "Photogeological Fault" should be used) is more commonly recognized. For this reason, the term "Fault" will be used instead of "Photolineaments" in this report.

In this project area, the geological structure trends toward the NNW-SSE direction and is very characteristic all over Peru. That is, (1) the arrangements of lithofacies, (2) elongate direction of faults and (3) of folding axes and (4) direction of minor fractures in this area trend to the NNW-SSE direction as mentioned above.

These facts are most important for the geological structure in this area.

However, the elongate directions of faults and folding axes are different in the rock forming age, and it is suggested that the geotectonic movements in this area are somewhat different from those in another age.

6-2 Folding

Distribution of folding axes interpreted on the airphotos are shown in the photogeological maps as ⓐ, ⓑ ----- and ⓩ. Moreover, an outline of the folding axes is also shown in Fig. 13.

As is evident from these figures, the folding axes observed in the project area are controlled by the geological structures trending in the NNW-SSE direction, which is very characteristic all over Peru as mentioned above. However, observing the distribution of the folding axes in several geological ages, it is recognized that there are obvious differences as follows.

(1) In the lower Jurassic-middle Cretaceous sedimentary rocks (unit 1, 2 and 3), the folding axes trending nearly in the N-S direction are predominant and each axis is short in length.

(2) In the upper Cretaceous sedimentary rocks (unit 4 and 5), the direction of folding axes is limited to the WNW-ESE direction only.

(3) In the Tertiary (unit 6, 7, and 8) and Quaternary sedimentary rocks (unit 16), the NNW-SSE direction, namely which resembles mostly the controlled direction of the geologic structure in this area, is super predominant.

These differences may suggest that the direction of the main folding activities are different in each geological age. In the Tertiary (unit 6, 7 and 8) and Quaternary (unit 16) sediments, there is no difference of direction in the folding axes. As for the reason, the following three ideas are considered;

(a) The folding activities in the Tertiary period have been nearly equal in direction to that of the Quaternary period.

(b) The folding both in the Tertiary and Quaternary period sediments have been formed by same folding activity at some stage, that is Quaternary period—after unit 16 had been formed.

(c) All of the folding in unit 6, 7, 8 and 16 are formed in the same age. That is, each of these units are Tertiary sediments.

However, (1) the relationship between unit 8 and 16 is unconformable, (2) unit 10 which is older in age than unit 16 covers unconformably unit 8 folded obviously and (3) unit 16 is stratigraphically superposed upon unit 15. Inferring these facts, it seems reasonable that ideas (b) and (c) are not suitable which idea (1) is suitable. However, in the case of unit 16, there is a possibility that the direction of folding axis had been strongly influenced by the topography of the basement rock.

6-3 Fault

1) Photolineaments which are equivalent to faults in photointerpretation are shown on the photogeological maps as No. ①, ② -----.

The distribution frequencies of faults are placed in more frequent order as follows; (1) the upper Jurassic-middle Cretaceous area, (2) the upper Cretaceous area, (3) the Tertiary area and (4) the Quaternary area. Namely, a sensible conclusion, the older the sediment, the more frequency, has been obtained. Moreover, in the area composed volcanic rocks, faults are very few.

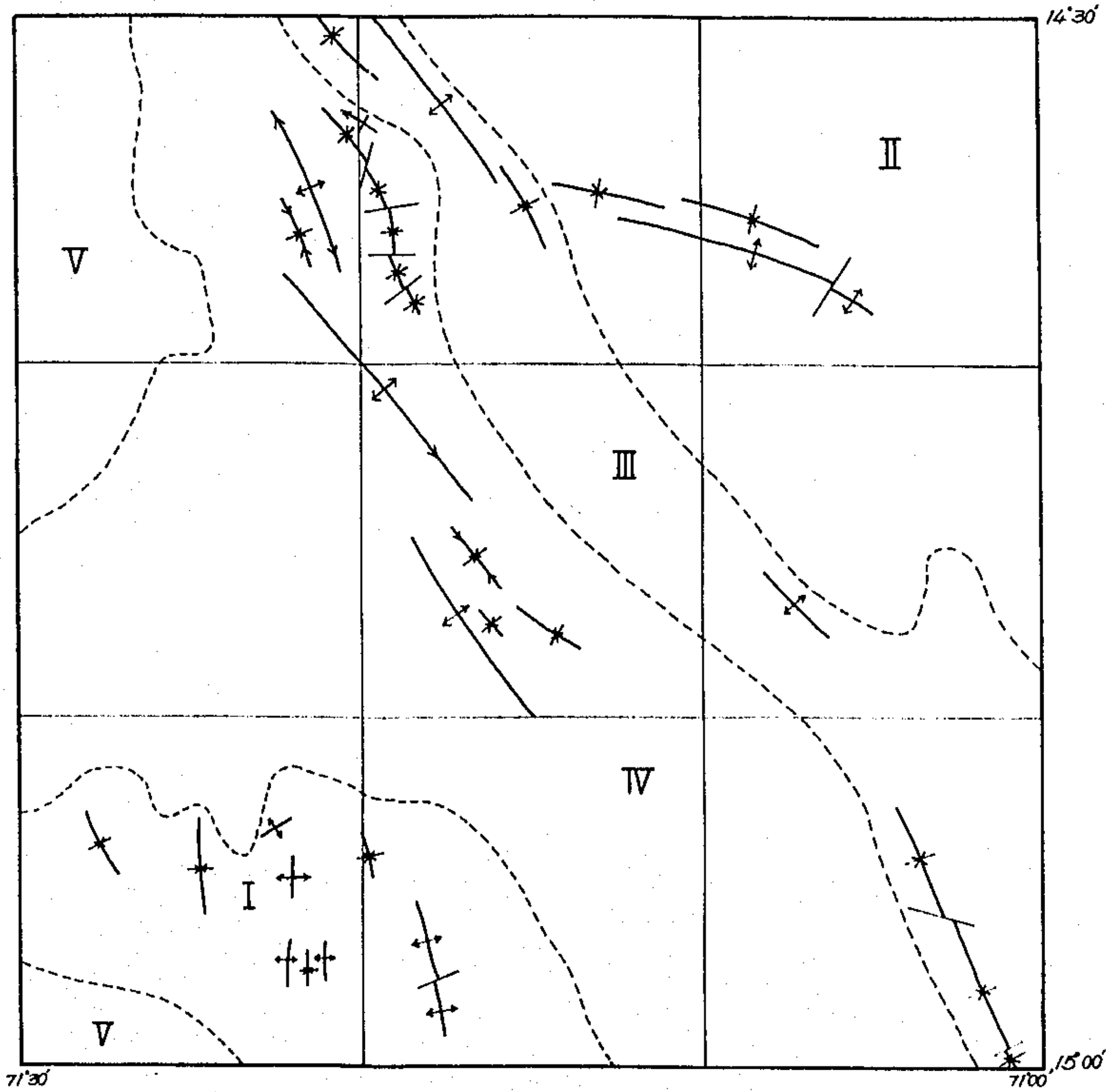
2) It is concluded that the series divided roughly into rock-forming ages (for example, the fault series between unit 4 and 8 and between the unit 8 and 16) are arranged predominantly in an NNW-SSE trending direction.

3) In the area composed of upper Jurassic-middle Cretaceous sediments, (1) the NNW-SSE trending fault and (2) the NE-SW trending fault are predominant. Generally speaking, the (2) faults are newer than the (1) in age.

4) In unit 4, (1) the NNW-SSE trending faults series are paralleled to the main geological structures, and (2) fault series conjugated against the (1) fault series are well developed. Especially, in the area surrounded by fault 15 and 16 , it seems that the strongly fractured and fault sheared zone (FZ) are formed because of compression from blocks on both side.

5) In unit 6, 7 and 8, the fault series of the Puno Group are divided into two, that is, (1) the fault trend to strike direction and (2) the fault cut diagonally to it. It seems that the fault (1) is newer than the (1) in age.

6) The fault series developed in unit 16, which is correlated in the Quaternary, show a distribution as cutting the folding axes in the same strata. This fact suggests that the folding movement had been roughly ahead of the fault movement in the geotectonic movements after forming unit 16.



I. Upper Jurassic——Middle Cretaceous Area
II. Upper Cretaceous Area
III. Tertiary Area
IV. Quaternary Area
V. Volcanic or Intrusive Rocks Area

(I–IV) Sedimentary Rocks Area

FIG.13 MAP SHOWING THE DISTRIBUTION OF FOLDING AXES IN THE EASTERN PART OF INVESTIGATED AREA (SHEET NO.5)

References

1) Blanchet, P.H., (1957) "Development of Fracture Analysis as Exploration Method"
Bull. Amer. Assoc. Petrol. Geol., Vol. 41, No. 8, 99.1748-1759

2) Lattman, L.H., (1958) "Technique of Mapping Geologic Fracture Traces and Lineaments on Aerial Phtographs"
Photogram. Engn. Vol. XXIV, PP. 568-576

3) Lattman and Nickelsen, R.P., (1958) "Photogeologic Fracture Trace Mapping in Appalachian Plateau"
Bull. Amer. Assos. Petrol. Geol. Vol 42, No. 9 PP. 2238-2245

4) Kupsh and Wild, (1958) "Lineament in Avonlea Area Saskatchwan"
Bull. Amer. Assos. Petrol. Geol. Vol. 42, No. 1, PP. 127-134

5) Von Bandad, (1960), "Aerogeology"
Gulf Publishing Company Houston, Texas

6) Miller, (1961), "Photogeology"
Mc GRAW-HILL BOOK Companz, Inc.

7) Hisaya Matsuno, (1965), "Photogeology"
Jitsugyo Kohosha Company in Tokyo Japan (Written in Japanese)

8) Servicio Narional de Geologia y Mineria, (1969) "Peru Mapa Metalogenetico 1:1,000,000"

9) Servicio de Geologia y Mineria (1969), "Sinopsis de la Geologia del Peru"
Republica del Peru, Ministerio de Energia y Minas