PART II DETAILED DISCUSSIONS

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CHAPTER 1 ANALYSIS OF EXISTING DATA

1 - 1 Compilation and Analysis of Material on Geology and Ore Deposits

1-1-1 Compilation and analysis of material

The geology and mineral deposits of the survey area are summarized as 1:1,000,000 scale geological and mineral resources maps by Servicio Nacional de Gelogia y Mineria (SERNAGEOMIN). Also the following more detailed maps were collected and knowledge necessary for satellite image analysis and geological survey were acquired.

Area	Scale	Lat.	Long.	Year of Issue	Publisher
Arica	1:300,000	17.5～19.25	68.9～70.4	1966	IIG
Collacagua	1:250,000	20.0～21.0	68.4～69.0	1984	SERNAGEOMIN
Pisagua y Zapiga	1:100,000	19.5～20.0	69.5～70.25	1977	IIG
Quillagua	1:250,000	21.0～22.0	69.0～70.5	1981	IIG
Ollagüe	1:250,000	21.0～22.0	68.0～69.0	1981	IIG
Juan de Morales	1:50,000	20.0～20.25	69.25～69.5	1968	IIG
Mamiña	1:50,000	20.0～20.25	69.0～69.25	1967	IIG
Alca	1:50,000	20.25～20.5	69.0～69.25	1962	IIG
Pica	1:50,000	20.25～20.5	69.25～69.5	1962	IIG
Chacarilla	1:50,000	20.5～20.75	69.0～69.25	1962	IIG
Matilla	1:50,000	20.5～20.75	69.25～69.5	1962	IIG

Stratigraphic table of the survey area was compiled from 1:1,000,000 scale geological map and is shown in Table 1-3-1. A geologic structure map was prepared from the above geologic map (Fig. 2-1-1).

Radiometric ages of the rocks are described in the explanatory texts of the Collacagua and Ollague sheet maps.

Data on mineral prospects and ore deposits are summarized in the explanatory texts of the 1:1,000,000 scale mineral resources map and also in the texts of Collacagua, Pisagua y Zapiga, Quillagua, Ollagüe, and Mamiña geological maps. Also for Cerro Colorado Deposit, the results of exploration by MMAJ is reported in "Overseas Geologic Structure Survey Report: Northern Chile (MMAJ, 1978). A list and distribution map of mines, ore deposits and mineral prospects was prepared from the above material (Table 2-1-1 and Figure 2-1-2).

J. Davidson and C. Mpodozis (1991) summarized the development of the igneous arc in the survey area. They have shown that the central axis of the igneous arc trending almost N-S moved eastward with time. Also the age of mineralization from Chile to southern Peru was studied by Clark et al., (1990) and Sillitoe (1991, 1992). It was clarified that two porphyry copper belts, namely the Paleocene-early Eocene western belt and the late Eocene-Early Oligocene eastern belt (Figs. 2-1-3, 2-1-4). Clarke et al., (1998) further inferred that giant porphyry copper deposits were formed in the relatively later stages of the late Eocene-early Oligocene mineralization. These results were compiled and shown in Figure 2-1-5.

The distribution of various geologic structure elements and classified mineral prospects and their relation to porphyry copper belt were compiled and laid out in geological and ore deposits analysis map (Fig. 2-1-6).

1-1-2 Digitization of information

The location of known ore deposits and mineral prospects and 1:1,000,000 scale geological map were digitized and transformed into ARC-View data. The mineral data are based on the geographic information from 1:500,000 scale topographic map and listing of mines, ore deposits and mineral prospect data (Table 2-1-1).

1 - 2 Image preparation, Geologic Interpretation, and Analysis of GEOSCAN Data

1-2-1 Objective of analysis

The objective of this analysis is to clarify the zoning of the alteration zones and the geologic structure from GEOSCAN data for extracting promising localities for ore occurrence.

1-2-2 Analyzed area

The areal extent of this analysis amount to a total of 2,550km² and the area consists of six sub-areas (Fig. 2-1-7).

1-2-3 Data used

The GEOSCAN data used were in ENVI (Environment for Visualizing Images) form and recorded in CD-ROM. Data of each scene consist of 1,024 pixels x 6,000~12,000 lines x 24 bands. The central wavelength of each band is shown in Table 2-1-2. There are 10 bands for visible near infrared region (0.4~1.5 μ m), eight bands for short-wavelength infrared region (1.5~3.0 μ m), and six bands for thermal infrared region (4~20 μ m).

The data for the analyzed area (2,550km^2) are of 17 scenes in six sub-areas (Table 2-1-3). (Data for band 17 of scene SF-19-2-7 could not be read from CD-ROM and thus were not used).

1-2-4 Preparation of images

The images prepared from GEOSCAN data are, as shown below; false-color images*1 using visible near infrared region~short-wavelength infrared region data, rationing images*2 and decorrelation stretch images*3of short-wavelength infrared region, and log residual images*4 and decorrelation stretch images.

After preparing the above images for the whole scenes, the parts for sub-areas were cut out (Table 2-1-3). Geometric corrections (tangential correction) and scaling were made on each scene in order to match the output images with 1:50,000 scale topographic map.

① Visible near infrared~short wavelength false color images (bands 1-2, 7-10, 11-18).
These are false color images prepared by allocating red, green, and blue to the average values of bands 1~2 and 7~10 of visual near infrared region and bands 11~18 0f short wavelength infrared region.

② Short wavelength infrared rationing images (bands 11/13, 11/14, 11/15)
These are images prepared by allocating red, green, and blue to each of the 11/13, 11/14, and 11/15 each rationing value.

③ Short wavelength infrared decorrelation stretch images (bands 12, 13, 14).
These are decorrelation stretch images prepared by allocating red, green, and blue to short wavelength infrared bands 12, 13, and 14.

④ Short wavelength infrared decorrelation stretch images (bands 14, 15, 16)
These are decorrelation stretch images prepared by allocating red, green, and blue to short wavelength infrared bands 14, 15, and 16.

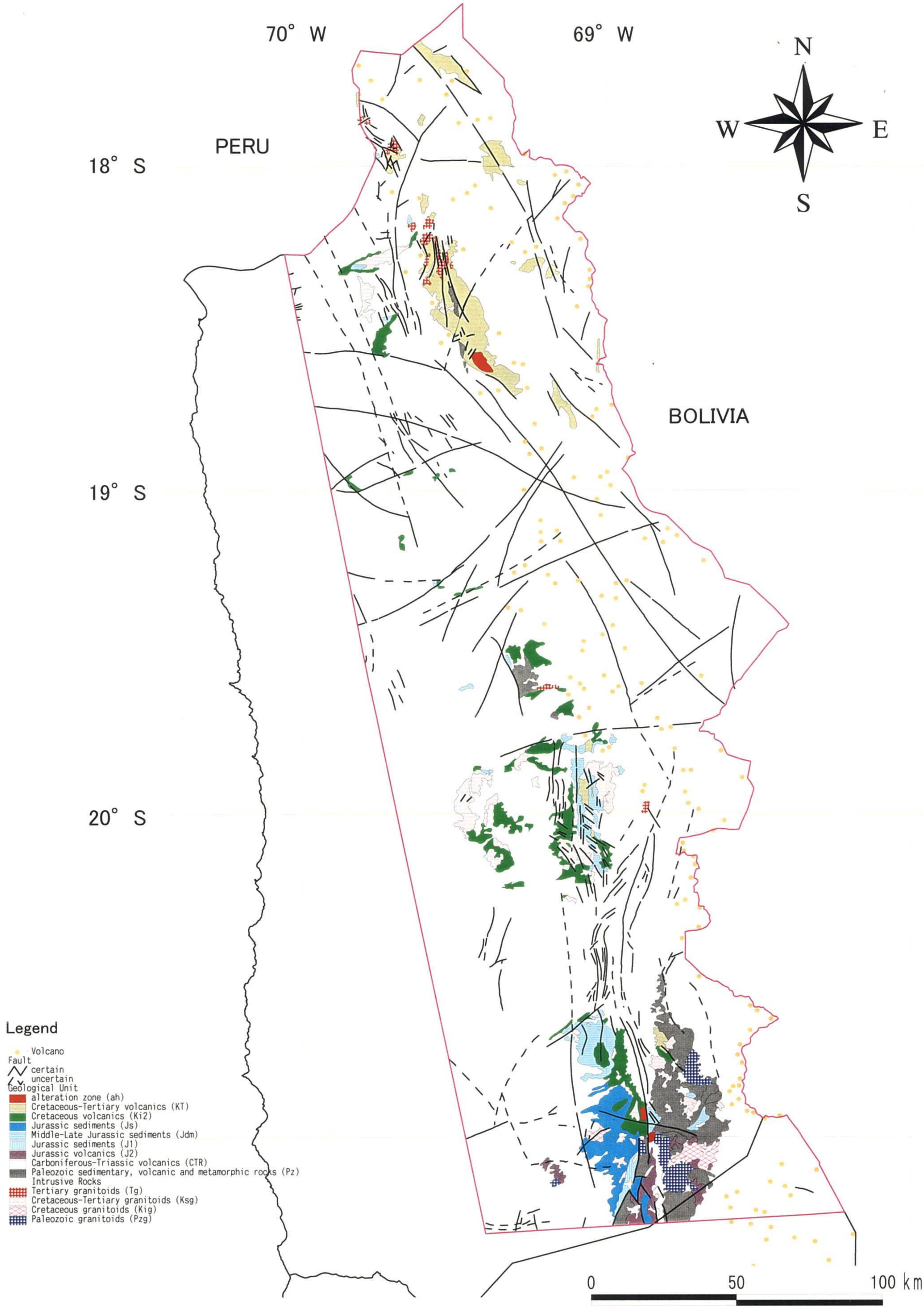


Fig. 2-1-1 Geological Structure of the Study Area

Table 2-1-1 List of Ore Deposits and Prospects in the Study Area

No.	Name	Location UTM N	Location UTM E	Type of Ore	Ore Mineral	Gangue Mineral	Form of Ore Deposit	Direction of Strike / Structure	Dip	Dimension Length × Width (m)	Wall Rock	Alteration	Ore Reserve (Million t / category)	Ore Grade	Type of Mineralization	Source of Data
1	Laguna Blanca	8043420	432447	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
2	Sicuni, Quiullere	8039549	432778	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
3	Culco(Bofadales de Chisllume)	8038318	428965	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
4	Ancara	8034543	425268	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
5	Carbunabe	8039923	446879	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
6	Culco(Bofadales de Chisllume)	8037173	453353	Mn			vein						*		Vein and Irregular-Mn	12
7	Kilometro 154	8023916	423931	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
8	Abundancia	8021611	428919	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
9	Ancolacani	8023959	436009	Mn			vein						*		Vein and Irregular-Mn	12
10	Locura	8019023	451066	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
11	Ancopujo	8021595	463877	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
12	San sebastian	8013079	425455	Fe			vein						*		Vein and Irregular-Fe	12
13	San sebastian	8010216	429172	Fe	Hem	Vitric materials	irregular, pocket	–	–	diameter: 300	Oxaya F. (tuff, lava)	?	*	Fe 52%	Vein and Irregular-Fe	8,12
14	Navidad	8009455	433198	Mn	Pyrolusite, Psilomelane	–	stringer, irregular, pocket	–	0	Thickness: 2-5, dia. 400	Huaylas F.	–	*	Mn 46%	Vein and Irregular-Mn	8,12
15	Este de Mina Navidad, Navidad Este	8009686	436161	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
16	Pascual	8009276	447173	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
17	Huachipato	8006674	428867	Mn	Pyrolusite, Psilomelane	silica	manto, irregular, pocket	–	–	5000 × 500, thickness 0.5	Huaylas F. (tuff)	–	*	Mn 17%, SiO2 45%	Stratiform-Mn	8,12
18	San Alberto	8005690	432152	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
19	Rosario	8002919	430891	Mn			stratiform						*		Stratiform-Mn	12
20	Kilometro 130	7997816	427206	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
21	Monica	7998156	474395	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
22	Rosario,Jamiralla	7982773	428531	Cu,Au	Chrysoc, Atac, Cc, Cup, Mal, Chalcanthite, Native Cu・Au	Tou, Qz	vein	0, 90		wd:<1/ 50 × 5	Gd	Ser, Kao, Lim, Qz, Tou	*	Rosario: Cu 5-30%	Vein and Irregular-Cu	8,12
23	Dos Hermanas	7977993	422735	Cu,Mo	Py, Cp, Mo, Bn	Qz, Adul, Bio	stockwork	340, 40, 85	90	–	Gd, Di-po	Chl, Ser, Clay, (Sil)	*	–	Porphyry-Cu,Mo	8,12
24	Evall	7974320	417677	Cu			irregular, pocket						*		Vein and Irregular-Cu	12
25	Camparani	7974350	425075	Cu,Au,W	Chrysoc, Atac, Mal, Cup, Cc, Scheelite, Hem, Mt, Lim	Jasper, Qz, Kao, Ser	stockwork	15	85E	100 × (0.1-0.5)	Tou.Breccia	Kao, Ser, Tou	*	–	Porphyry-Cu,Au	8,12
26	Choquelimpie	7979891	467760	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
27	Choquelimpie	7978352	474950	Ag,Pb,Zn(Au)			stockwork						*		Unknown-Ag,Pb,Zn	12
28	Choquelimpie	7973252	467560	Au,Ag,Pb,Zn,(Cu)	Arg, Py, Cp, Sp, Gn, Realgar	Qz, Ba, Cal	vein, hydrothermal breccias: high sulfidation	–	–	length: 140-710	Lupica F. (lava, breccia, conglo.), Di-po	Py	*	Au 29.4g/t, Ag 730g/t	Vein-Ag,Pb,Zn	8,9,12
29	Churiguaya	7971061	485631	Cu	Native Cu, Cup, Chrysoc	–	irregular, pocket	–	–	15 × 3	Andesitic lava	Hydrothermally altered	*	–	Vein-Ag,Pb,Zn	8,12
30	Lucita, Halcones	7960608	419637	Cu			vein						*		Vein and Irregular-Cu	12
31	El Milagro	7960478	445616	Cu			stratiform						*		Stratiform-Cu	12
32	Patino	7960158	450052	Ag,Pb,Zn,Cu			vein						*		Vein-Ag,Pb,Zn	12
33	Campanani	7952077	448701	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
34	Capitana	7948984	450715	Mn			no record								Unknown-Mn	12
35	Churicala	7947977	446391	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
36	San Lorenzo	7959614	453539	Pb,Zn,Ag,Cu	Py, Cp, Sp, Tet, Gn	Qz, Ba	vein	0	–	150 × 0.5	Lupica F. (Ad, conglo.), Di, Qz-po	Kao, Py, Lim	*	Pb 33%, Zn 17%, Ag 500g/t	Vein-Ag,Pb,Zn	8,12
37	Santa Rosa	7945999	451567	Ag,Pb,Zn	Py, Cp, Gn, Sp, Cerus, Angl	Qz, Clay	vein	280	90	140 × 1	Lupica F. (volcanics), Di-po	Hydrothermally altered	*	2 samples from gallery: Pb 8-13%, Ag 320g/t, Au 1g/t	Vein-Ag,Pb,Zn	8,12
38	Apalacheta	7949882	455673	Ag,Sb			vein						*		Vein-Sb	12
39	Churicala Norte, Churicala Sur	7942025	455269	Cu,Ag			vein						*		Vein and Irregular-Cu	12
40	Chulpa, Trinidad	7942591	481282	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
41	Capitana	7940133	450843	Pb,Zn,Ag,Cu,Sn,Bi	Py, Apy, Gn, Sp,	Clay, Qz	vein, lens	350-10	60-80W	wd: 15	Lupica F. (volcanics), Di	Hydrothermally altered	*	–	Vein-Ag,Pb,Zn	8,12
42	Ociel	7936591	450431	Ag,Sb	Py, Stib, Apy	Qz, Clay	vein	40	90	wd: 0.5	Lupica F. (volcanics)	?	*	–	Vein-Sb	8,12
43	Ociel	7937844	466565	Sb			vein						*		Vein-Sb	12
44	Taruguire	7912512	470613	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
45	Surire	7910206	486203	Mn			irregular, pocket						*		Vein and Irregular-Mn	12
46	Taltepe	7898947	414005	Cu			vein						*		Vein and Irregular-Cu	12
47	Sta. Ana	7898963	417584	Cu			vein						*		Vein and Irregular-Cu	12
48	El Sapte	7847446	469457	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
49	Sapte	7841905	465060	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
50	San Pedro	7840463	463069	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
51	Quebrada Quacesina	7830628	470430	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
52	Guacesina	7830637	476616	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
53	Paguanta	7815491	493190	Ag,Pb,Cu			vein						*		Vein-Ag,Pb,Zn	12
54	Limacsina	7811388	481879	Ag			vein						*		Vein-Ag,Pb,Zn	12
55	Sta. Rita, San Antonio	7811272	476851	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
56	Beatriz, Chile, Independencia, Chipamani(ex-San Antonio), Pascuala	7812053	471303	Cu,Au			vein						*		Vein and Irregular-Cu	12
57	Maria Ines, Pascuala (Mocha)	7809543	471489	Cu,Au			vein, stockwork						60	Cu 0.4%	Porphyry-Cu,Au	12
58	San Juan de Mocha	7806845	470195	Cu,Au			vein						*		Vein and Irregular-Cu	12
59	San Enrique, Llulla, Nueva Victoria, Tres Marias, Tres Puntas	7806844	475705	Cu (Au,Ag)			vein						*		Vein and Irregular-Cu	12
60	Subercagua	7803737	470265	Ag,Pb,Zn			vein						*		Vein-Ag,Pb,Zn	12
61	Sta. Fe	7802305	474141	Cu			no record								Unknown-Cu	12
62	Sta.Fe, Colpa	7802844	479899	Cu			no record								Unknown-Cu	12
63	Mosquito de Oro	7804426	495498	Au			no record								Unknown-Au	12
64	Chana, Sta. Rosa	7805865	499476	Au,Cu			vein						*		Vein and Irregular-Cu	12
65	Ollarapu	7798892	493406	Fe			vein						*		Vein and Irregular-Fe	12
66	Queen Elizabeth, Rosa, Cucho	7802777	502766	Cu			vein, stockwork						*		Porphyry-Cu	12
67	Violeta	7788453	463386	Ag,Pb			vein						*		Vein-Ag,Pb,Zn	12
68	Cerro Colorado	7783600	472286	Cu,Mo	Cc, Brochantite, Chrysoc, Atac, Mal, Cup, Teno, Dioptase, Antl, Chalcan, Turq, Cov, Py, Mo, Hem, Lim, Mt, Chromian spinel	Qz, Tou, Gyp, Alb, Or, Ser, Kao, Pyroph, Alu, Mont, Jar, Alunogen	stockwork	ENE-WSW	–	X(1000 × 800)	Andesitic tuff, Qz-po, Dac/Trachy-po, Breccia, Ad	Sil, Ser, Py, (Alu), Tou, Prop	204	Cu 1.02%	Porphyry-Cu,Mo	1,5,6,12
69	Amilca	7783104	475862	Cu,Au	Py, Hem, Cu-oxi, Au	–	vein	330	60E	–	Ad, Congl (Cerro Empexa F.)	?	*	–	Vein and Irregular-Cu	11,12
70	San Marcos	7783855	482657	Cu,Ag,Pb	Gn, Sp, Cp, (Cup, Cc, Mal)	Ba, Qz	vein / manto	320-30	25NE-20NW	wd: 1	Sa, Brec (Cerro Empexa F.)	Propilitic	*	Cu 2.9%, Pb 2%, Ag 190g/t	Vein-Ag,Pb,Zn	11,12
71	Flor del Desierto	7783848	486599	Cu,Ag,Pb,Zn	Py, Cp, Hem, Cu-oxi	–	stockwork (porphyry Cu)	–	–	–	Rhyo-stock, Ad(Cret)	Ser, Kao, Prop	*	–	Porphyry-Cu	11,12

No.	Name	Location UTM N	Location UTM E	Type of Ore	Ore Mineral	Gangue Mineral	Form of Ore Deposit	Direction of Strike / Structure	Dip	Dimension Length × Width (m)	Wall Rock	Alteration	Ore Reserve (Million t / category)	Ore Grade	Type of Mineralization	Source of Data
72	Lallinca	7783369	487091	Cu	Cc, Cup, Chrysoc, Mal	Qz, Tou	vein	340	60E	(80-100) × (1-1.5)	Ad (Cerro Empexa F.)	Chl, Epi	-	-	Vein and Irregular-Cu	11,12
73	San Andres	7782619	484000	Ag,Pb,Zn	Py, Apy, Cp, Sp, Gn	Qz	vein	0	75W	100 × 1	Gd	Chl, Kao	s	-	Vein-Ag,Pb,Zn	11,12
74	Gualchagua	7782416	492364	Cu	Cup, Chrysoc, Cu-oxi	-	vein	60	90	-	Chacarilla F. (Jur)	?	s	-	Vein and Irregular-Cu	11,12
75	Columtucsa	7779416	496236	Cu	Cc, Py, Chrysoc	Tou	irregular vein	NW	-	-	Gd	Kao	-	-	Vein and Irregular-Cu	11,12
76	Sagasca, Molibdeno Cerro Colorado	7770192	462693	Cu,Mo	Chrysoc	-	stockwork, dissemination : exotic	-	-	Thickness: 10-30	Conglomerate (Altos de Pica F.)	-	>10	Cu 2.5%	Porphyry-Cu,Mo	6,12
77	Sagasca	7767871	464475	Cu			irregular, pocket						s		Vein and Irregular-Cu	12
78	Mina Pila	7772025	491127	Zn,Pb,Sb,As,Cu	Sp, Gn, Py, Stib, Apy, Cp	Qz, Ba, Cal	vein	340	45NE	300 × (1-2)	Meta-ad. (Mesoz)	Chl, Epi, Kao,	Probable: 0.01	Au 2.9g/t, Ag 550g/t, Pb 3.3%	Vein-Ag,Pb,Zn	11,12
79	Mollaca, Rio Tinto S	7772986	479410	Cu,Ag			vein						s		Vein and Irregular-Cu	12
80	Yabricoya	7774217	492227	Zn,Pb,Cu,Sb,Ag	Sp, Gn, Py, Cp, Stib, Arg?	Qz, Ba	vein	300	80NE	wd: 0.5	Gd-po, Di	Kao	s	gallery 380m: Ag 310g/t, Pb 3%	Vein-Ag,Pb,Zn	11,12
81	Rio Tinto	7774761	483380	Cu	Cc, Teno, Chrysoc, Hem	Qz, Tou	vein	65	70SE	250 × (0.6-1)	Gd	Kao	s	U/G: Cu 12.8%, Ag 50g/t, Au 0.4g/t	Vein and Irregular-Cu	12
82	Rio Tinto Norte	7776014	483168	Cu	Cp, Bn, Py, Chrysoc, Teno	Tou	vein	70	35N	(50-60) × 0.5	Gd	Chl, Kao	s	-	Vein and Irregular-Cu	12
83	Luisa	7776910	486755	Pb,Cu,Zn	Gn, Tet, Sp, Py, Angl, Chrysoc	Tou, Qz, Ba	vein	330-335	20-25NE	100 × (0.5-1)	Gd-Adam	Tou, Sil, Kao	0.004	U/G Probable: Au 3.4g/t, Ag 870g/t, Pb 8.3%	Vein-Ag,Pb,Zn	11,12
84	Luisa de Canulpa	7776423	485783	Ag,Au,Pb,Zn			vein						s		Vein-Ag,Pb,Zn	12
85	Zoila Rosa	7774655	489652	Cu,Ag,Pb,Zn,Au	Gn, Py	Cal	vein	330	30NE	20 × 0.7	Ad, Gd	?	s	gallery 20m & incline 30m: Au 8-1.6g/t, Ag 92-630g/t, Pb 1.6-3.5%	Vein-Ag,Pb,Zn	11,12
86	Aguada, San Felix, Rosario, Fortuna	7774545	491638	Cu,Ag,Pb,Zn			vein						s		Vein-Ag,Pb,Zn	12
87	Tigre-San Carlos	7773463	490112	Cu	Cc, Cup, Native Cu, Chrysoc, Teno, Cp	Tou	breccia pipe	-	-	-	Meta-ad, Gd	Tou	s	-	Porphyry-Cu	11,12
88	Labranza	7770113	495967	Cu	Py, Cp	-	vein	90	40S	wd: 0.5	Gd, Rhyo-po	Kao	>0.01	dump: Au 5-10g/t, Ag 60g/t, Cu 3.5%	Vein and Irregular-Cu	11,12
89	Santiago	7769899	495716	Cu			vein						s		Vein and Irregular-Cu	12
90	La Planada	7770086	492991	Cu,Au,Mo	Mo, Py, Cp, Cc, Cov, Cup, Chrysoc, Hem	Tou, Qz	breccia pipe, porphyry copper	-	-	-	Rhyodac-po	Ser(marginal), kao(central)	m	Cu 20%	Porphyry-Cu,Mo	11,12
91	Infiernillo	7769188	484605	Cu	Cc, Hem, Chrysoc,	Qz	irregular vein	NW	90	-	Ad, congl.	Epi	-	-	Vein and Irregular-Cu	11,12
92	Hundida	7769089	492444	Cu	Chrysoc, Mal, Cc, Cup	Tou, Qz	dissemination, irregular, breccia	NNW	-	140 × ?	Rhyodac-po	fresh	-	-	Porphyry-Cu	11,12
93	Arauco	7768622	492700	Cu	Cup, Cc, Chrysoc, Mal	Tou, Qz	breccia pipe	-	-	-	Rhyodac-po	Tou, Chl	-	gallery 10m: Cu 14.8%, Au 1.5g/t, Ag 13g/t	Porphyry-Cu	11,12
94	Sofia	7767535	487512	Ag (Au,Pb,Zn)	Chrysoc	Qz	? (oxide Cu)	-	-	-	Congl, Ad	?	s	pit & adit 70m: Cu 5-6%	Unknown-AgPbZn	11,12
95	Jauja	7772794	485348	Ag,Au,Pb,Zn,As, Cu	Py, Apy, Sp, Cp, Bn, Tet, Gn	Qz, Cal	vein	290-315	60-75SW	250 × (0.5-1.5)	Di	Kao	0.01	U/G: Au 5.4g/t, Ag 476g/t, Pb 7%, Zn 15%	Vein-Ag,Pb,Zn	11,12
96	Rio Tinto S, Jauja	7766238	481821	Cu,Ag,Au,Pb,Zn			vein						s		Vein-Ag,Pb,Zn	11,12
97	Sitilca	7764884	492559	Cu,Au	Py, Cp, hem, Chrysoc	Qz	vein	0	50W	150 × 0.2	Sedim. & volcanics (Cret)	?	s	Adits: Cu 5%, Au 20g/t	Vein and Irregular-Cu	11,12
98	Carmela	7729293	440784	Fe			vein						s		Vein and Irregular-Fe	12
99	Vicuna de Punta Malla, Punta Malla II	7729939	518662	Ag,Cu	Gn, Cu-oxi, Hem, Lim	Qz	vein	10	60N	200 × 0.5	Ss, Rhy dyke		s	Cu 5.7%, Ag 105g/t	Vein and Irregular-Cu	12,13
100	Punta Malla	7729497	518349	Ag,Cu	Mal, Azur, Hem	-	vein	300	76N	10 × 0.8	Ad		s	-	Vein and Irregular-Cu	13
101	Empexa (Alona)	7718107	502292	Cu	Cu-oxi, Hem	Qz	vein	0	30E	100 × 0.4	Ad		s	Cu 4%	Vein and Irregular-Cu	12,13
102	Caballuno	7712902	511665	Cu	Cp, Cc, Cu-oxi, Py, Hem	Qz	vein	0	70E	120 × 1	Ad(Paleoz), Gd(Tert)	Prop, Clay	s	Oxi. Ore: Cu 5%	Vein and Irregular-Cu	12,13
103	Longacho	7710893	526347	Cu	Chrysoc, Mal, Lim, Hem	-	-	90	70S	wd: 0.5-1	Gd		-	-	Unknown-Cu	13
104	San Antonio	7706930	502291	Ag	Mn-oxi, Lim	Qz	-	320	30N	wd: 1	Ad		-	Ag 1762g/t	Unknown-Ag,Pb,Zn	13
105	Rosario,(Cerro Campana)	7705823	504060	Au	Au, Lim, Hem	Qz	vein	70	48N	-	Gd, Dac-po: Tert	Clay, Sil	s	-	Vein-Au	12,13
106	Carmen	7706598	501770	Au	Au, Lim	Qz	vein	310	60N	50 × 0.3	Ad		s	Au 2.5g/t	Vein-Au	13
107	San Miguel	7701499	516132	Au,Ag,Cu,Pb,Zn	Gn, Cp, Bn, Cu-oxi	-	vein	90	80S	70 × 1	Gd		s	Pb 2.25%, Au 2g/t	Vein-Ag,Pb,Zn	12,13
108	Pasaca	7698399	517066	Au,Ag,Cu	Ag, Au, Cu-oxi	-	vein	80	80S	100 × ?	Gd		s	Ag 87g/t	Vein and Irregular-Cu	12,13
109	Pastillas	7697712	532986	Au	Au	Qz	vein	0	80E	800 × 3	Gr		s	-	Vein-Au	12,13
110	Vicuna	7696292	520810	Mn	Mn-oxi., Lim	Ba	-	320	60N	wd: 1	Dac		-	-	Unknown-Mn	13
111	Majala	7690992	495631	Cu			no record								Unknown-Cu	12
112	Copaquire, (Establecimiento Copaquire, Quebrada Huiquintipa), Sulfatos	7687116	511023	Mo,Cu	Chalcanthite, Atac, Au, (Cp, Py)	-	stockwork	0	-	Altered zone: 2500 × 600	Gd, Gd/Monz-po, Altered qz(dac)-po : E.Tert	Center: Qz-Ser, Bio, Periphery: Py, Sil, Epi	m	Copaquire: 27million t -Mo 0.077%, Sulfatos: Cu 0.5-1.6%, Mo 95g/t	Porphyry-Cu,Mo	12,13
113	Condor	7686337	515598	Cu	Cu-oxi	Qz	-	15	90	-	Ad		-	Cu 2-3%	Unknown-Cu	13
114	Flor de Tarapaca (Alta)	7691758	518100	Ag,Pb,Cu	Gn, Cu-oxi, Ag, Hem	Ba	vein	65	85S	150 × 0.5	Ad		s	Pb 4.9%, Ag 493g/t	Vein-Ag,Pb,Zn	12,13
115	Flor de Tarapaca Baja	7691757	519036	Pb,Cu,Ag	Gn, Cp, Arg, Cerus, Cu-oxi, Py	Qz	vein	75	80N	1 × 1	Ad		s	-	Vein-Ag,Pb,Zn	13
116	Malta	7685015	507694	Mo	Mo, Cp, Cu-oxi, Py	Gyp	vein	315	55S	300 × 1.5	Gd		s	Mo 0.3%	Vein-Mo	12,13
117	Colcol	7684131	503119	Ag,Pb,Zn,Cu	Gn, Sp, Arg, Cu-oxi, Lim	Qz	vein	90	55S	100 × 0.5	Red ss		s	Pb 30%, Ag 300g/t	Vein-Ag,Pb,Zn	12,13
118	Hunquintipa	7681456	525053	Ag,Pb	Gn	Ba	vein	75	43NW	50 × 0.3	Ad		-	Ag 75g/t	Vein-Ag,Pb,Zn	13
119	Hunquintipa	7682682	518298	Cu			irregular, pocket: exotic				Gravel		s		Vein and Irregular-Cu	12
120	Huiquintipa	7683558	525680	Cu			no record						8	Cu 1.43%	Unknown-Cu	4,12
121	Lolon	7681091	458522	Ag,Au,Pb			vein						s		Vein-Ag,Pb,Zn	12
122	Challacollo	7682210	463614	Ag			vein						s		Vein-Ag,Pb,Zn	12
123	San Guillermo de Catigna, Catigna	7679813	491996	Cu			vein						s		Vein and Irregular-Cu	12
124	Las Porfiadas	7679482	495426	Cu			vein						s		Vein and Irregular-Cu	12
125	Yamincha	7681586	500208	Cu, Mn	Cu-oxi		vein	30	65S	-	Red ss, Ad dyke		s	-	Vein and Irregular-Cu	12,13
126	Abundancia, Aurora, Carmen, Quebrada Blanca	7678696	519852	Cu			vein						s		Vein and Irregular-Cu	12
127	Aurora	7680021	522868	Cu			vein						s		Vein and Irregular-Cu	12

No.	Name	Location UTM N	Location UTM E	Type of Ore	Ore Mineral	Gangue Mineral	Form of Ore Deposit	Direction of Strike / Structure	Dip	Dimension Length × Width (m)	Wall Rock	Alteration	Ore Reserve (Million t / category)	Ore Grade	Type of Mineralization	Source of Data
128	Tarapaca	7680008	530768	Cu, Au?	Chrysoc, Au?, Specu, Lim	Qz	vein/stockwork	340	90	60 × 4.5	Ad, Dac-po		–	–	Porphyry-Cu,Au	12,13
129	Don Manuel	7679677	529936	Au, Mn	Au, Mn-oxi, Lim	Qz	vein/stockwork	0-342	90	470 × 1.5	Ad		–	–	Vein-Au	12,13
130	Esperanza	7679012	530455	Cu, Au	Chrysoc, Atac, Turq, Chenev, Au		vein/stockwork	336	90	Wd: 1-3	Dac-po		–	–	Porphyry-Cu,Au	12,13
131	Forasteras	7678791	530246	Au,Cu	Au, Mal, Chrysoc, Chenev, Lim	Qz	vein	312	70S	Wd: 1-4	Dac-po		–	–	Vein and Irregular-Cu	12,13
132	Anita	7678349	530038	Au, Ag	Au, Specu, Lim	Qz	vein	20	63N	800 × 2	Dac-po		Possible: 1	Au 7.6g/t, Ag 100g/t	Vein-Au	12,13
133	Rosario (Collahuasi),	7681445	531395	Cu,Mo	Cp, Cc, Mo, Chrysoc, Mal, Py, Lim	Qz	vein/stockwork	NW-SE	–	Altered zone: 2500 × 1000	Dac-po(Olig)	Ser, Prop, (U/G: Mt, Bio, Kf, Chl	Rosario, supergene enriched ore:50	Cu 1.5%	Porphyry-Cu,Mo	3,4,9,12,13
					Alongside but higher than porph. Cu: En							Alongside but higher than Por. Cu: (Qz-Alu)	Rosario, primary ore: 710	Cu 0.93%		
134	Ujina (Collahuasi)	7675008	540008	Cu			stockwork						supergene enriched ore:>100	Cu 2%	Porphyry-Cu	3,4
													Ujina, primary ore: 1266	Cu 0.78%		
135	Venus	7680891	532121	Cu	Cp, Cc, Bn, Chrysoc, Mal, Py, Lim	Qz	vein/stockwork?	–	–	–	Dac-po, Ad				Porphyry-Cu	12,13
136	Ponderosa	7680448	532225	Cu	Cp, Bn, Tet, Cc, Chrysoc, Mal, Py, Lim	Qz	stockwork?	320	70S	wd: 13	Dac-po		Possible: 0.5	Cu 8%, Ag 60g/t, Au 1g/t	Porphyry-Cu	12,13
137	San Carlos	7680226	532432	Cu	Cp, Bn, Cc, Chrysoc, Turq, Py, Lim	Qz		300	73S	wd: 9	Altered po		–	Cu 18.7%	Unknown-Cu	12,13
138	Jilguero	7679008	532534	Cu	Chrysoc, Mal, Lim	Qz	vein?	330	90	wd: 1.5	Gd-po		–	–	Vein and Irregular-Cu	12,13
139	Tinque	7678788	531806	Cu	Chrysoc, Mal, Lim	–	vein?	–	–	–	Dac-po		–	–	Vein and Irregular-Cu	12,13
140	Las Granadas	7673614	490544	Cu			vein						s		Vein and Irregular-Cu	12
141	Quebrada Blanca	7674166	512158	Cu,Mo	Lim, Py, Cp, Mo, Bn, Cu-oxi		stockwork			Altered zone: 7km^2, Mineralized zone (E-W): 2000 × 1000m Leaced zone: 80-100m, Sec. Enriched zone: 30-100m	Qz-Monz(Olig), Dac/Rhyo-po	Prop, Clay, Qz-Ser, Sil, Bio, (Kf), Tou	supergene enriched ore: 90	Cu 1.3%,	Porphyry-Cu,Mo	2,3,7,12
													primary ore: 400	Cu 0.5%, Au 0.1g/t, Ag 1-2g/t, Mo 0.015%		
142	Yareta, Yaretita	7675704	523174	Ag,Au,Mn			vein						s		Vein-Au	12
143	Jovita	7681561	528484	Cu	Cc, Bn, Cov, Chrysoc, Mal	–	vein	NW	90	–	Altered po		s	–	Vein and Irregular-Cu	12,13
144	Ingenio	7681450	529108	Fe	Py, Lim	Qz	–	NW	90	–	Altered po		–	–	Unknown-Fe	12,13
145	Trinidad	7674592	526706	Ag,Mn	Mn-oxi., Lim	Qz	vein	280	90S	100 × 0.5	Gd		s	Mn 15.3%, Ag 808g/t, Au 2.37g/t	Vein-Au	12,13
146	Moctezuma, (Borracha)	7674922	527538	Ag, Au,Cu,Mn	Psilomelane, Pyrolusite		vein	350	80S	300 × 2	Dac-po, Ad		>2	Mn 10%, Ag 250g/t, Au 2g/t	Vein-Au	12,13
147	San Nicolas	7679902	527962	Cu, Mn, Au	Chrysoc, Atac, Mn-oxi, Lim	Qz	vein	300	90	600 × 5	Dac		–	–	Vein and Irregular-Cu	12,13
148	Anita	7664311	482242	Cu,Au			vein						s		Vein and Irregular-Cu	12
149	Sud-America	7678349	529830	Cu	Chrysoc, Mal, Turq, Chenev, Au, Lim, Mn-oxi	Qz	vein	10	80W	400 × 1	Dac-po		–	–	Vein and Irregular-Cu	12,13
150	Pergolesi	7678238	530038	Cu	Cp, Cc, Chrysoc, Mal, Au, Py, Lim	Qz	vein	30	70N	wd: 5	Ad, Tuff		–	–	Vein and Irregular-Cu	12,13
151	Delirio	7678127	530349	Cu, Au	Cp, Cc, Chrysoc, Mal, Au, Py, Lim	Qz	vein	0	90	wd: 4	Ad, Dac-po		–	–	Vein and Irregular-Cu	12,13
152	Los Caciques	7677904	531492	Au	Au, Lim, Mn-oxi	Qz	vein	339	90	wd: 1	Dac		–	–	Vein-Au	12,13
153	Japonesa	7677575	529725	Cu	Cp, Cov, Enar, Chrysoc, Chenev, Py, Lim	Qz	vein	NW	90	wd: 0.3	Dac, Ad		–	–	Vein and Irregular-Cu	12,13
154	La Borracha	7677353	530036	Cu	Chrysoc, Atac, Lim	Qz	vein	350	40E	wd: 1	Ad		–	–	Vein and Irregular-Cu	12,13
155	Dulcinea	7676467	530242	Cu	Chrysoc, Mal, Lim	Qz	vein	320	75N	wd: 1	Rhy-po		–	–	Vein and Irregular-Cu	12,13
156	Quilahuena	7661652	480064	Cu,AU	Chrysoc, Au, Lim	Qz	vein	32	69E	40 × 2	Cret (contact of Gd)	–	Probable: 0.002, Possible: 0.006	?	Vein and Irregular-Cu	10,12
157	Pirula	7666309	489718	Ag,Pb			no record								Unknown-Ag,Pb,Zn	12
158	Capona, (Quebrada de Mani)	7668524	492625	Au,Ag,Cu	Gn, Py, Lim, Chalcanthite	Gyp	vein	100	80N	200 × (0.1-0.7)	Jur, Tert	–	Probable: 0.002	Ag 15-1000g/t, Pb 1-36%	Vein and Irregular-Cu	10,12
159	Olqa, Lorena, Caniqueta	7668305	502181	Cu,Au			stockwork						s		Porphyry-Cu,Au	12
160	Julia	7665195	518486	Cu			no record								Unknown-Cu	12
161	Tres Marias, (La Peruana)	7665185	526379	Cu	Cu-oxi	–	vein	45	90	wd: 1-2	Gd		s	–	Vein and Irregular-Cu	12
162	Gales	7665183	527210	Cu	Cu-oxi	–	vein	305	90	wd: 1	Rhy-po		s	–	Vein and Irregular-Cu	12
163	La Esperanza	7663970	524923	Cu	Cu-oxi	–	vein	–	–	4 × 1	Gd		s	–	Vein and Irregular-Cu	12
164	Conacona	7661971	528970	Au			vein						s		Vein-Au	12
165	Macata	7658894	510381	Cu			no record								Unknown-Cu	12
166	Chocal	7651477	512452	Au			no record								Unknown-Au	12
167	Jovita	7671392	519844	Cu		–	vein			–			s	–	Vein and Irregular-Cu	12
168	Santa Rosa (Queen Elizabeth)	7801352	501079	Cu			vein, stockwork						s		Porphyry-Cu	12
169	Cucho (Queen Elizabeth)	7803746	503302	Cu			vein, stockwork						s		Porphyry-Cu	12

Abbreviation (Table 2-1-1)

<Ore Mineral>

Angl	Anglesite
Antl	Antlerite
Apy	Arsenopyrite
Arg	Argentite
Atac	Atacamite
Azur	Azurite
Bn	Bornite
Cc	Chalcocite
Cerus	Cerussite
Chalcan	Chalcanthite
Chenev	Chenevixite
Chrysoc	Chrysocolla
Cov	Covelline
Cp	Chalcopyrite
Cup	Cuprite
Enar	Enargite
Gn	Galena
Hem	Hematite
Lim	Limonite
Mal	Malachite
Mo	Molybdenite
Mt	Magnetite
Oxi	Oxide
Py	Pyrite
Sp	Sphalerite
Specu	Specularite
Stib	Stibnite
Teno	Tenorite
Tet	Tetrahedrite
Turq	Turquiose

<Gangue Mineral>

Adul	Adularia
Alb	Albite
Alu	Alunite
Ba	Barite
Bio	Biotite
Cal	Calcite
Gyp	Gypsum
Jar	Jarosite
Kao	Kaolinite
Mont	Montmorillonite
Or	Orthoclase
Pyroph	Pyrophyllite
Qz	Quartz
Ser	Sericite
Tou	Tourmaline

<Wall Rock>

Ad	Andesite
Adam	Adamellite
Congl	Conglomerate
Dac	Dacite
Di	Diorite
Gd	Granodiorite
Monz	Monzonite
Po	porphyry
Rhyo	Rhyolite
Rhyodac	Rhyodacite
Sedim	Sedimentary
Ss	Sandstone
Trachy	Trachytic
Tert	Tertiary
Olig	Oligocene
Mesoz	Mesozoic
Cret	Cretaceous
Jur	Jurassic
Paleoz	Paleozoic

<Alteration>

Chl	Chlorite
Epi	Epidote
Kao	Kaoline
Kf	K-feldspar
Lim	Limonite
Mt	Magnetite
Prop	Propyritization
Py	Pyrite
Qz	Quartz
Ser	Sericite
Sil	Silicification
Tou	Tourmaline
u/g	Underground

<Type of Mineralization>

Ir	Irregular, pocket
Por	Porphyry
St	Stratiform
Unk	Unknown
Ve	Vein

<Category of Ore Reserve>

Metal (ore grade)	s	m	
Cu *1	<10,000	10,000-	10,000
Au *1	<2	2-	200
Ag *1	<60	60-	6,000
Mn(48%) *2	<100,000	100,000-	10,000,000
Fe(60%) *2	<500,000	500,000-	50,000,000
Pb *1	<25,000	25,000-	2,500,000
Zn *1	<20,000	20,000-	2,000,000

*1 fine metal (t)
*2 ore reserve (t)

<Source of Data>

1 Canadian Minilng Journal (2000)
2 Mineral Yearbook (1997)
3 Mining Magazine (1992)
4 Mining Magazine (1999)
5 MMAJ (1978)
6 Olivier C. (1968)
7 Ramirez C. and Huete C. (1981)
8 Salas R., Kast R., Montecinos F. and Salas I. (1966)
9 Sillitoe R. (1991)
10 Skarmeta J. and Marinoic N. (1981)
11 Thomas A. (1967)
12 Ulriksen C. (1990)
13 Vergana H, and Thomas A. (1984)

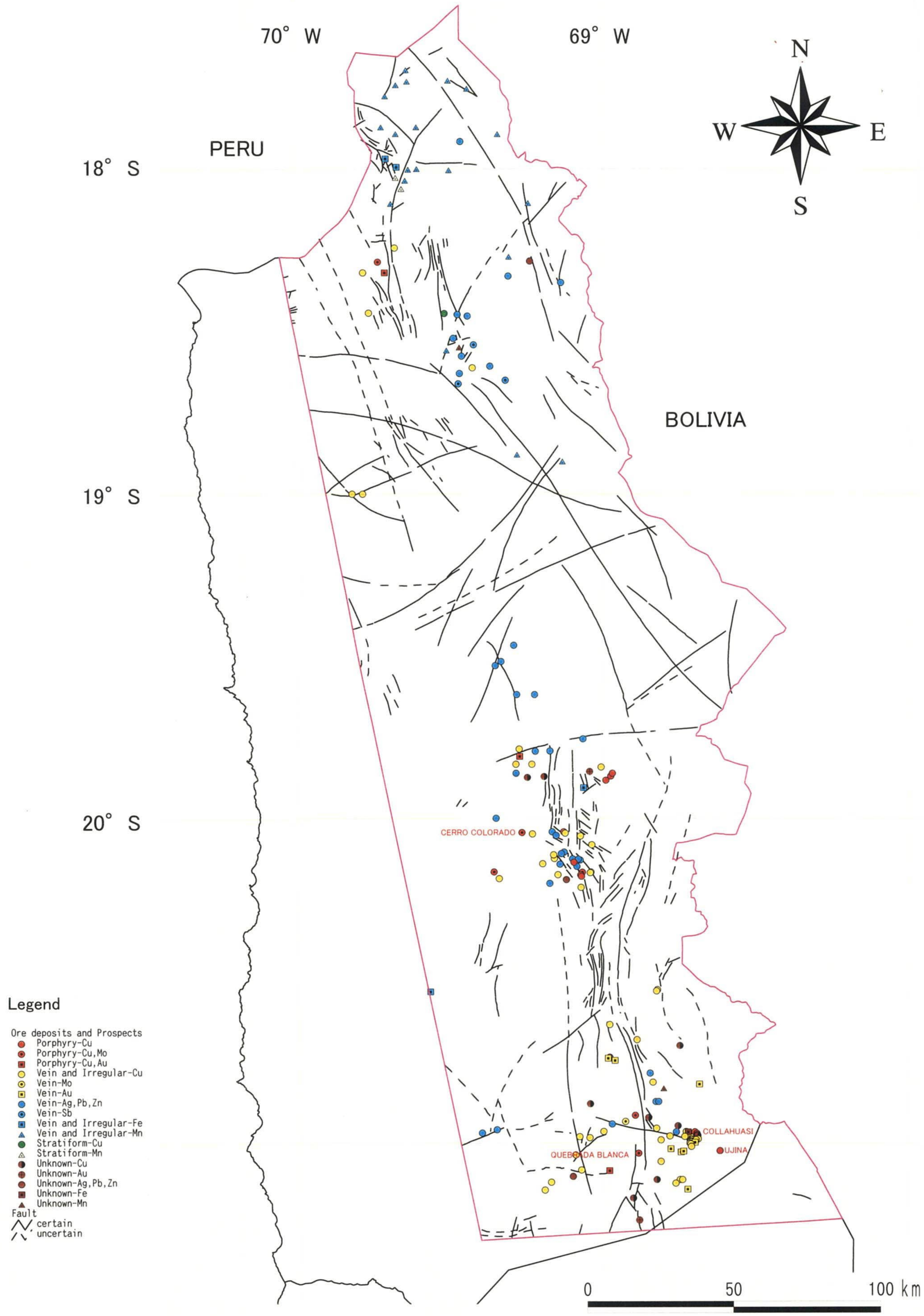


Fig. 2-1-2 Distribution of Ore Deposits and Prospects in the Study Area

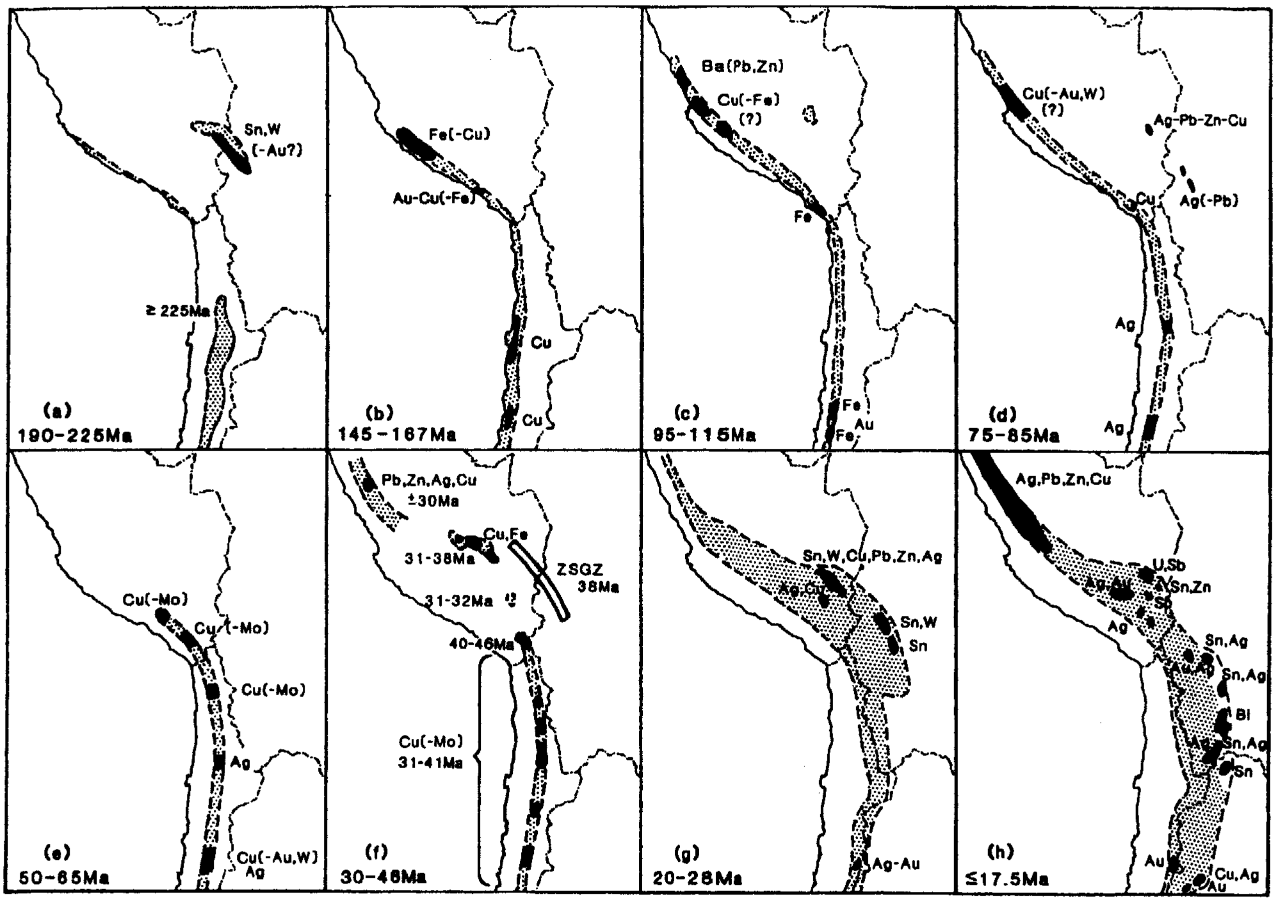


Fig. 2-1-3 Sketch Maps Showing Areas in the Central Andes Affected by Selected Mesozoic and Cenozoic Magmatic and Metallogenic Episodes

Shading delimits approximate volcano-plutonic domains and black areas represent the more important, or in some cases, metallogenically significant, mineralizations.

Radiometric ages are given (f) for the several regions contributing to the critical 30 to 46 Ma. episode; ZSGZ represents the Zongo-Sán Gabán tectono-thermal zone of Farrar et al. (1988).

Map "a" incorporates the location of the Permo-Triassic volcano-plutonic belt of northern Chile, emplacement of which had terminated prior to the intrusion of the Carabaya batholith in the study transect.

(after Clark et al., 1990)

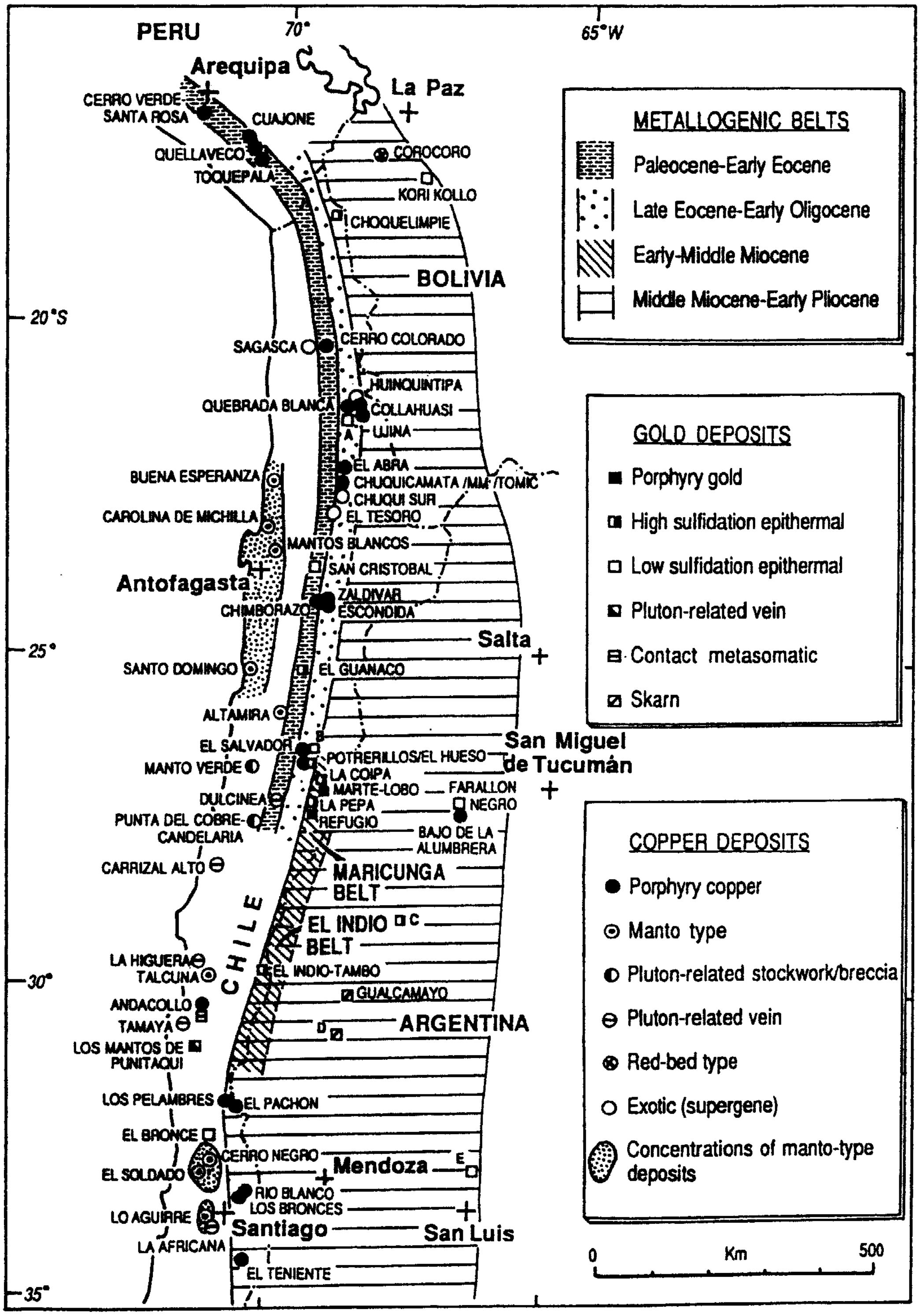


Fig. 2-1-4 Types of Principal Gold and Copper Deposits in the Central Andes

Principal deposits, defined arbitrarily to contain >10 metric tons Au or >100,000 metric tons Cu, are named. Metallogenic belts adapted from Sillitoe (1990, 1991). Minor deposits and prospects referred to in text are marked by letters: A=Choja, B=Tinajas, C=La Mejicana, D=Carolina. (after Sillitoe, 1992)

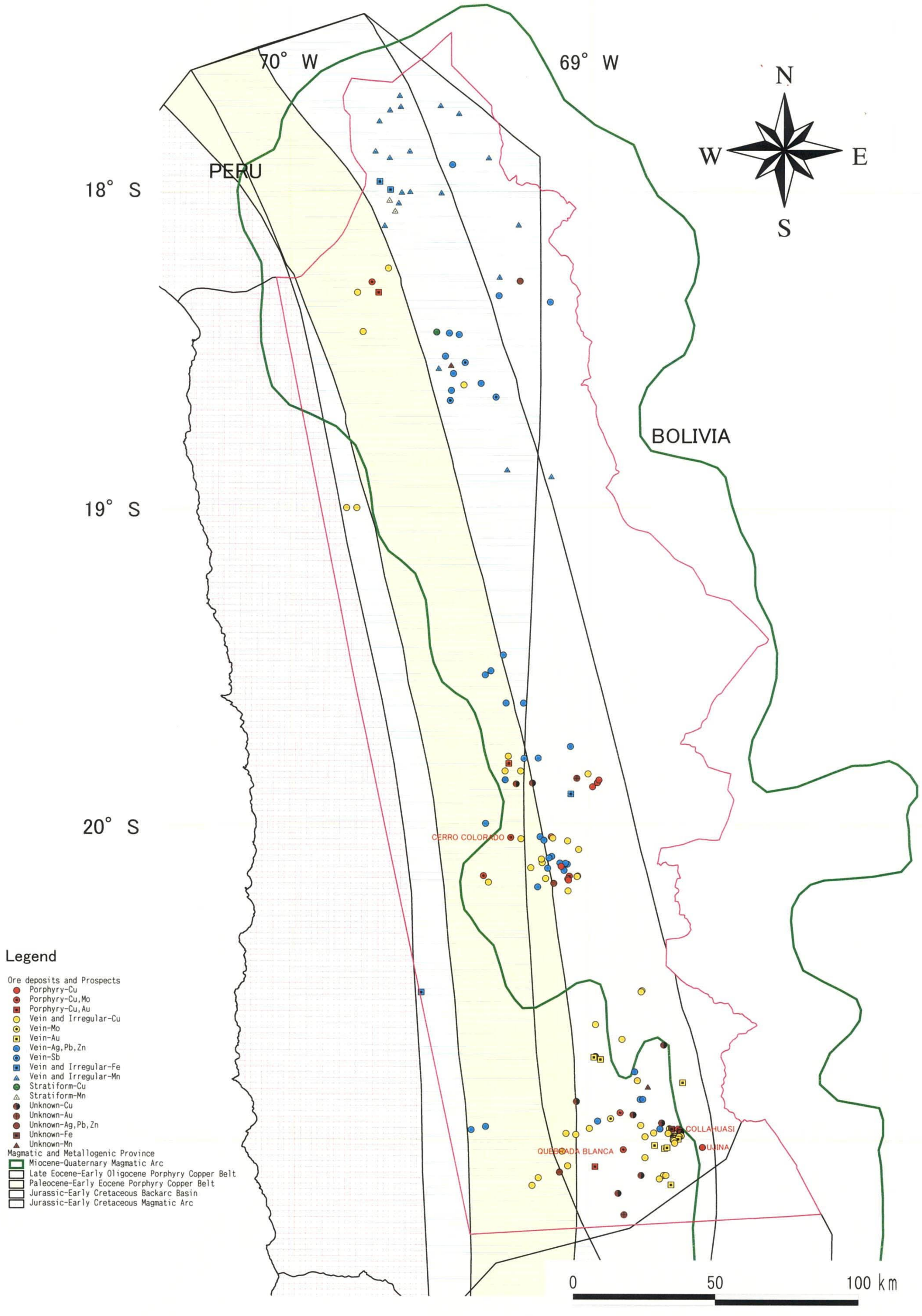


Fig. 2-1-5 Magmatic and Metallogenic Province in the Region I Area

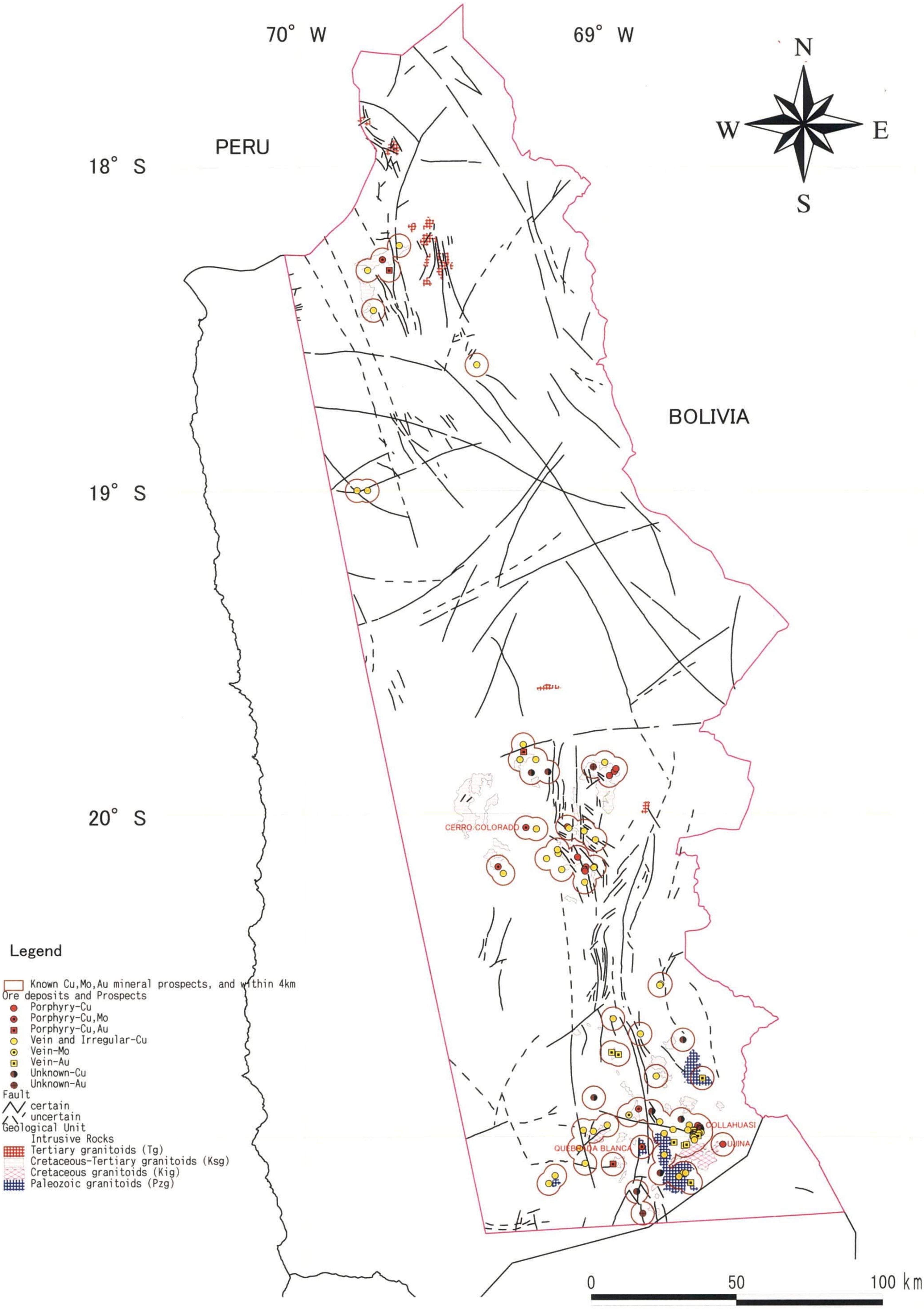


Fig. 2-1-6 Compiled Interpretation Map from Previous Data of the Study Area

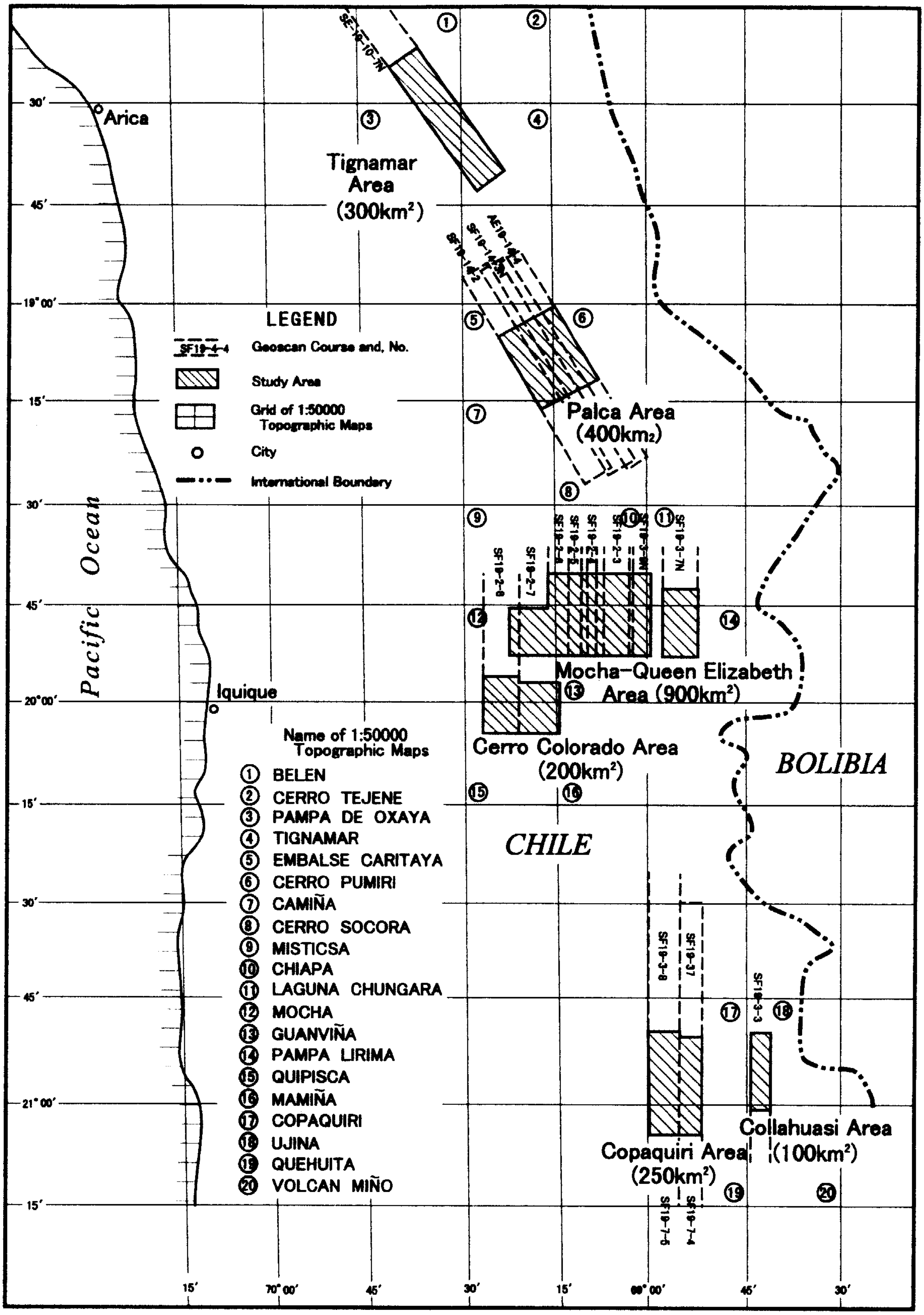


Fig. 2-1-7 Location Map of Geoscan Images

⑤ Thermal infrared log residual images (bands 20, 22, 24)

These are log residual images prepared by allocating red, green, and blue to thermal infrared bands 20, 22, and 24.

⑥ Thermal infrared decorrelation images (bands 20, 22, 24)

These are decorrelation stretch images prepared by allocating red, green, and blue to thermal infrared bands 20, 22, and 24.

*1) False color images

For multi-colored images, color images can be prepared by allocating different colors to images of each band and these are called false color images. Normally three primary colors are allocated to three bands (or three processing results).

*2) Rationing

Three combinations of two bands from many bands and their ratios are calculated, and three primary colors are allocated to each to each of them. This is called rationing process. The major objective of this exercise is to eliminate the topographic information (effect of sunrays) from the data and to enhance the spectral information.

*3) Decorrelation stretch

In multi-band images, correlation among data of each band is high and the false color images cannot express the geology by diverse colors. On the other hand, almost all of the information contained in the raw image data can be expressed by a small number of imaginary bands (data compression) using principal component analysis. Thus the colors of the images processed by principal component analysis will be diverse. The problem with this method is the inference of the geology by color. Decorrelation stretch processing is to enhance hue and saturation component keeping original color balance to the new bands acquired by principal component analysis. Kahle et al., (1983) distinguished silicified rocks, argillaceous rocks, and carbonate rocks in decorrelation stretch images prepared from Thermal Infrared Multispectral Scanner (TIMS) data.

*4) Log residual

Log residual is a method of normalizing the target area by average values. It calls for converting observed values to emissivity patterns. The outline of the method is as follows.

Table 2-1-2 Band Allocation of GEOSCAN Data

Band	Central wavelength [μm]	Band	Central wavelength [μm]
1	0.522	13	2.123
2	0.583	14	2.154
3	0.645	15	2.220
4	0.693	16	2.255
5	0.717	17	2.301
6	0.740	18	2.346
7	0.830	19	8.640
8	0.873	20	9.170
9	0.915	21	9.700
10	0.955	22	10.220
11	2.031	23	10.750
12	2.083	24	11.280

Table 2-1-3 List of GEOSCAN Data Used for Interpretation

Area	Scene	Pixel	Line	Line width used for interpretation	Num. of line
Tignamar	SE-19-10_7N	1,024	11,786	1 - 6,700	6,700
Palca	SE-19-14_4	1,024	7,473	2,001 - 5,500	3,500
	SE-19-14_3N	1,024	7,733	2,001 - 5,500	3,500
	SE-19-14_2	1,024	7,910	2,501 - 6,000	3,500
Copaquiri	SF-19-7_5	1,024	7,026	1 - 1,400	1,400
	SF-19-7_4	1,024	9,566	1 - 1,900	1,900
	SF-19-3_8	1,024	12,116	1 - 2,400	2,400
	SF-19-3_7	1,024	8,077	1 - 2,400	2,400
Collahuasi	SF-19-3_3	1,024	6,582	1 - 2,800	2,800
Cerro Colorado	SF-19-2_8	1,024	5,668	2,001 - 3,300	1,300
	SF-19-2_7	1,024	6,080	2,401 - 3,700	1,300
Mocha-Queen Elizabeth	SF-19-2_7	1,024	6,080	1 - 1,800	1,800
	SF-19-2_6R	1,024	8,882	5,301 - 8,300	3,000
	SF-19-2_5	1,024	11,645	1,001 - 5,000	4,000
	SF-19-2_4	1,024	11,795	1,101 - 5,100	4,000
	SF-19-2_3	1,024	12,117	7,901 - 11,900	4,000
	SF-19-3_9N	1,024	12,117	7,801 - 11,800	4,000
	SF-19-3_7N	1,024	12,116	8,717 - 12,116	3,400

Table 2-1-4 Wavelength for Calculation of Reflentance and Emissivity

Band	GEOSCAN Central wavelength [μm]	Wavelength for calculation [μm]
1	0.522	0.4915 - 0.5525
2	0.583	0.5520 - 0.6140
3	0.645	0.6210 - 0.6690
4	0.693	0.6810 - 0.7050
5	0.717	0.7055 - 0.7285
6	0.740	0.6950 - 0.7850
7	0.830	0.8085 - 0.8515
8	0.873	0.8520 - 0.8940
9	0.915	0.8950 - 0.9350
10	0.955	0.9350 - 0.9750
11	2.031	2.0050 - 2.0570
12	2.083	2.0630 - 2.1030
13	2.123	2.1075 - 2.1385
14	2.154	2.1210 - 2.1870
15	2.220	2.2025 - 2.2375
16	2.255	2.2320 - 2.2780
17	2.301	2.2785 - 2.3235
18	2.346	2.3235 - 2.3685
19	8.640	8.3750 - 8.9050
20	9.170	8.9050 - 9.4350
21	9.700	9.4400 - 9.9600
22	10.220	9.9550 - 10.4850
23	10.750	10.4850 - 11.0150
24	11.280	11.0150 - 11.5450

It is assumed that, in thermal infrared region, the radiance observed by sensors can be expressed as a product of reflectivity of earth materials, radiance of black body, and effect of atmosphere (transparency and other factors). Thus it is assumed that the following equation holds, when observed value is $X_{i\lambda}$ for band λ of pixel i.

$$X_{i\lambda} = \varepsilon_{i\lambda} \cdot B_i(T) \cdot I_\lambda \qquad (1)$$

$\varepsilon_{i\lambda}$ is the earth surface reflectivity of band λ corresponding to pixel i. $B_I(T)$ is the black body radiance at surface temperature T of pixel i and is assumed that it is not dependent on wavelength (band). I_λ expresses the effect of atmosphere to band λ, and is assumed that it is constant within an image for one band. Now if the number of pixels of each band is M and the number of bands N, geometric means for i direction

$$(X_{i\lambda}/X_{i.})/(X_{.\lambda}/X_{..}) = (\varepsilon_{i\lambda}/\varepsilon_{i.})/(\varepsilon_{.\lambda}/\varepsilon_{..}) \qquad (2)$$

The left side of equation (2) consists of observed values of each pixel and their geometric mean value, and the right side of the equation consists only of terms related to emissivity. Namely, normalization by geometric mean theoretically will eliminate the effect of surface temperature and atmosphere. Now when the apparent emissivity of the right side of equation (2) is ε', ε' can be obtained by the following equation (Yamaguchi et al., 1989).

$$\log \varepsilon' = \log X_{i\lambda} - \log X_{i.} - \log X_{.\lambda} + \log X_{..} \qquad (3)$$

$$X_{i.} = \left(\prod_{\lambda}^{N} X_{i\lambda}\right)^{1/N}$$

$$X_{.\lambda} = \left(\prod_{i}^{M} X_{i\lambda}\right)^{1/M}$$

$$X_{..} = \left(\prod_{i}^{M}\prod_{\lambda}^{N} X_{i\lambda}\right)^{1/MN}$$

1-2-5 Spectral data

Reflection spectra of major rocks and minerals were obtained for selecting bands in image preparation. The used data set is "MMAJ Spectral database Ver. 3.0" and "JPL Spectral Library". The spectra of each band were obtained by arithmetic mean of observed band width shown in Table 2-1-4. The reflection spectra of rock and mineral samples are laid out in Figure 2-1-8.

- For short-wavelength infrared region, absorption (decrease of reflectivity) is observed at bands 13, 14, and 15 for sulfate and clay minerals (Fig. 2-1-8). Therefore, rationing images of bands 11/13, 11/14, and 11/15, and decorrelation stretch images for bands 12, 13, 14, and combination of 14, 15, and 16 were prepared in order to extract clay minerals and alteration zones.

- For thermal infrared region, absorption spectra of rocks vary with SiO_2 content (MMAJ 2000). Band 20 is absorbed by silicified rocks (Fig. 2-1-8). Thus log residual and decorrelation stretch images of combination of bands 20, 22, and 24 were prepared for extracting silicified rocks.

1-2-6 Characteristics of prepared images

The color characteristics of prepared images of Cerro Colorado are described below.

① False color images of visible near infrared to short-wave infrared region (bands 1-2, 7-10, 11-18)
Compared with geological maps, it is seen that areas of sedimentary rocks are shown in blue to greyish blue, and andesitic and granitic bodies are expressed by bluish green hue. The alteration zones are pale whitish color in the images.

② Rationing images of short-wavelength infrared region (bands 11/13, 11/14, 11/15)
The sedimentary rocks are shown in dark blue, andesitic and granitic rocks in bluish to yellow. Also alteration zones are shown in light blue.

③ Decorrelation stretch images of short-wavelength infrared region (bands 12, 13, 14)
Alteration zones are shown in many colors, namely sericite-rich parts in yellow, kaolin and alunite-rich parts in red to orange. It is seen from the spectral pattern of these bands that the minerals are expressed in these colors.

④ Decorrelation stretch images of short-wavelength infrared region (bands 14, 15, 16)
The sercite and kaolin-rich parts are shown in dark blue in these images. Areas inferred to be rich in smectite are reddish purple.

⑤ Log residual images of thermal infrared region (bands 20, 22, 24)
Silicified rocks are shown in greenish blue.

⑥ Discorrelation stretch images of thermal infrared region (bands 20, 22, 24)
Silicified rocks are shown in light blue.

Alteration zones extracted from short-wavelength infrared rationing images, short-wavelength decorrelation stretch images (bands 12, 13, 14 and 14, 15, 16) are significantly wider than those extracted by thermal infrared log residual images and thermal infrared decorrelation stretch images. The reason for the above is believed to be scattering of fragile alteration minerals in the vicinity of alteration zones by wind, water and other natural elements and the reaction to these scattered zones.

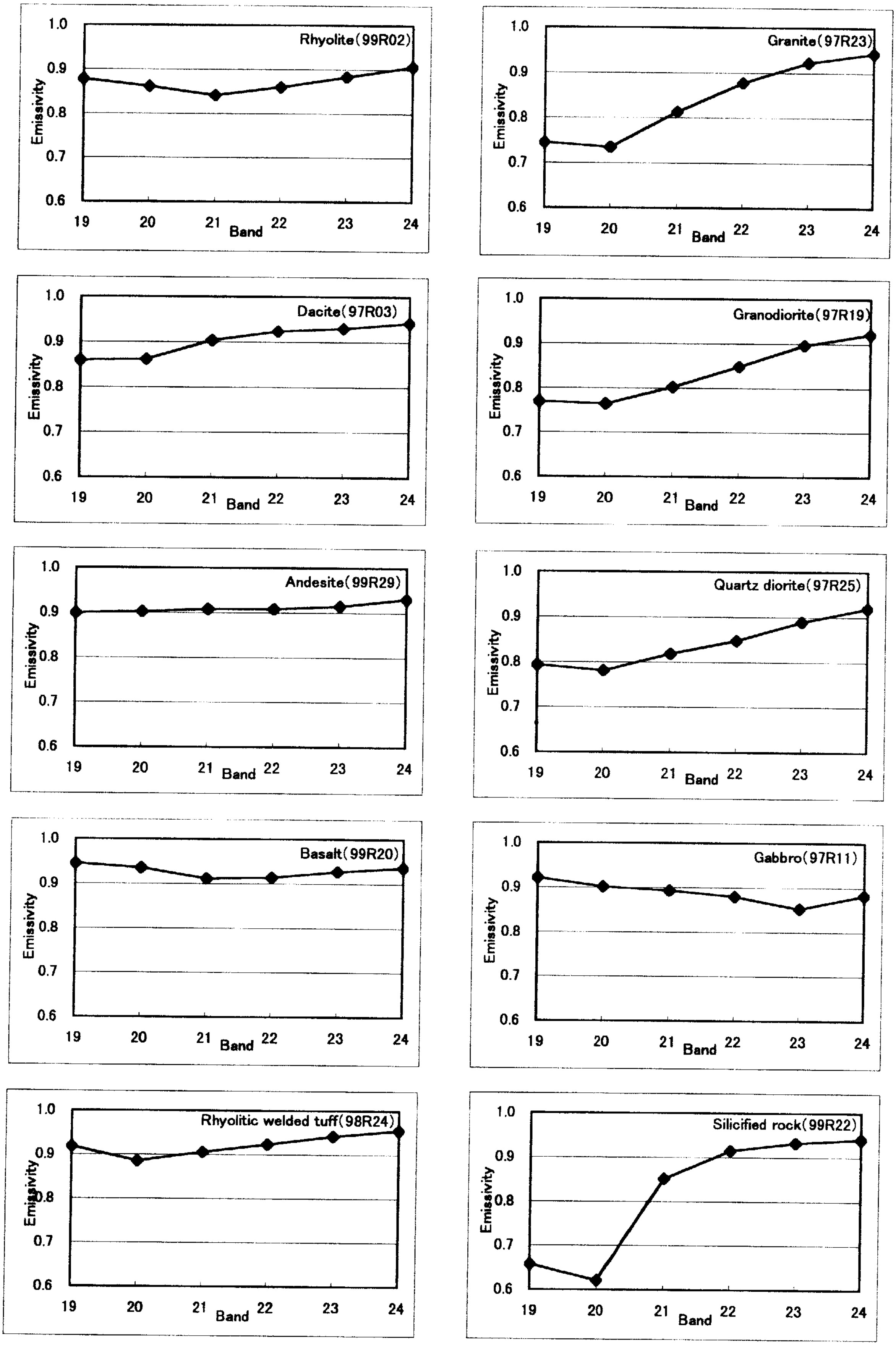


Fig. 2-1-8 Reflectance – Emissivity of rock and mineral samples (1)

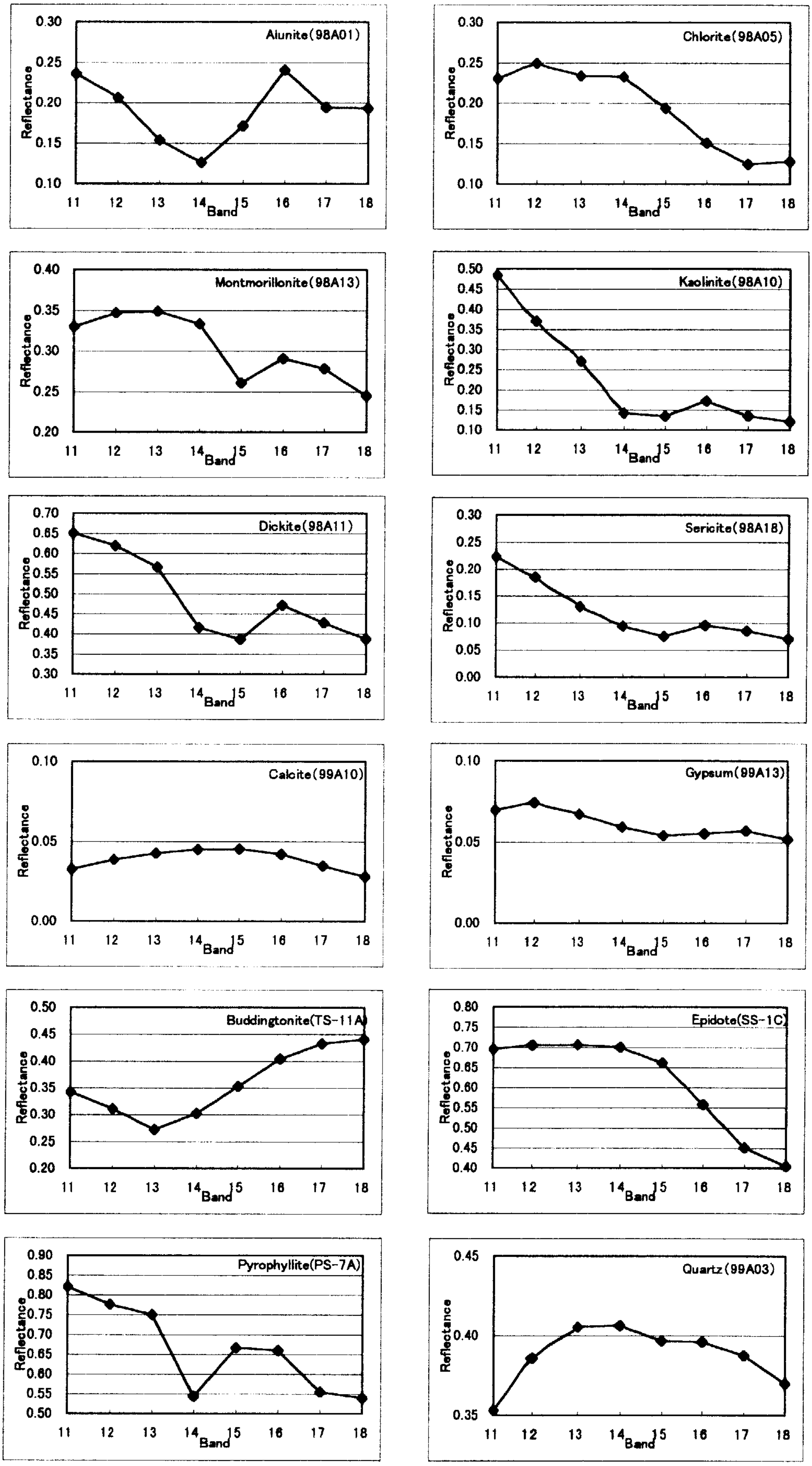


Fig. 2-1-8 Reflectance - Emissivity of rock and mineral samples (2)

1-2-7 Photogeological interpretation and analysis of GEOSCAN images

The Geological interpretation map of each sub-area is shown in Plates 6-11. In addition, the geological stratigraphic classification of the sub-areas is shown in Table 1-3-1 and results of photogeological interpretation are shown in Table 2-1-5. Photogeological interpretation of each geological unit, structural characteristics and alteration zones of each area are described as follows.

(1) Tignamar sub-area

1) Delineation of geologic units

Geologic units of this area are composed of Paleozoic semi-schists (Pz), Cretaceous volcanic rocks (K_2), Tertiary pyroclastic rocks (Ti3 and Ti4) , Quaternary unconsolidated sediments (Qal and Qtl) and intrusive rocks (Tgd).

These units are mainly distributed as follows.

Qal : Along the main river
Qtl : Central part and along the main river of the northeastern part
Ti4 : Southwestern part
Ti3 : Northwestern part (1km×1km in scale as a elliptical shape)
K2 : Almost whole area
Pz : Northeastern part (NNE-SSW zonal distribution on a rough scale of 2km×7km)
Tgd : Central part (nearly 0.5km×2km in scale)

Characteristics of each unit and a correlation with existing geologic maps are shown in Table 2-1-6.

2) Structural characteristics

(a) Lineaments and faults

The following four elements are enumerated as the morphological features used for identifying lineaments in the present area.

① Notably winding flow of rivers
② Linear continuation of break points of slopes
③ Notably linear flow of rivers
④ Linear pattern caused by tone difference

A total of 58 lineaments are extracted from this area.
Most of these lineaments are distributed in Unit K2. (Only three lineaments are extracted in Units Ti3 and Ti4)

The largest lineament is observed at the boundary of Unit Pz and K2, and is about 8km long trending in the NNE-SSW direction.

Besides this, there are three lineaments about 5km long and others are about 1-2km.

Regarding the direction of lineament, NE-SW system is dominant with intersecting NNW-SSE and NW-SE systems. A high lineament density zone is observed from the central northern part to the western central part of the area.

(b) Folding
Folding is not observed in this area.

(c) Annular structure, caldera and dome structure
Only one semi-annular structure of about 1km in diameter is observed in the northeastern part of the study area in Unit K2. The tone of Unit K2 in this part is slightly different from other areas. Remarkable bedding is not developed in the surrounding strata. Therefore, the annular structure does not indicate the top of the anticline, but it is possible that concealed intrusive rock exist under the Unit K2. Other annular structures, calderas and dome structures are not observed.

3) Alteration zones
A total of 53 alteration zones were extracted as from Geoscan false color Images as shown in PL. 6-A. Of these, 48 zones are observed in Unit K2, and five zones in Unit Ti4.

A high density part of the alteration zone exists at the western central part in Unit K2 and the south-westernmost part in Unit Ti4. In the former, largest alteration zone is about 0.5km × 1.0km in scale, and the zones are scattered within the range of 5km × 8km. In the latter, the alteration zones are about 0.3km × 1.9km in scale, the zones are concentrated within the range of 3km × 4km.

On the other hand, alteration zones extracted from the ratio images, the decorrelation stretched images (bands 12,13,14 and 14,15,16), and the thermal logarithmic residual images have similar distribution pattern of alteration zones extracted from the false color composite images as shown in PL. 6-B.

Regarding the alteration minerals, sericite is commonly observed, kaolin-alunite are observed in the southwestern, the western central the north-easternmost parts. Smectite is observed in the central part. Of these, in the kaolin-alunite zone in the southwestern part, the characteristic greenish blue part suggesting the siliceous rock on the thermal logarithmic residual image is observed. Existence of kaolin-alunite shows the possibility that this greenish blue part corresponds to the silicified zone.

An direct relationship between the distribution of lineaments and the alteration zones is not shown.

(2) Palca sub-area

1) Delineation of geologic units

The relationship of the superposition of stratum is comparatively easily distinguished from the geomorphological characteristics and tracing of bedding on Geoscan false color composite images in this area.

Geologic units of this area are divided broadly into two groups of Unit Tv correlated with the Tertiary volcanic rocks and Unit Q correlated with the Quaternary unconsolidated sediments. Unit Tv is subdivided to Tva, Tvb1, Tvb2, and Tvc, and Unit Q is subdivided to Qs, Qf, Qtl and Qal from lower horizon upward respectively. Of these, Unit Tvb1 is most widely distributed, and composed of volcanic rocks. Unit Tvb2 is inferred to be ignimbrite intercalated in Unit Tvb1.

Characteristics of each unit and a correlation with existing geologic maps are shown in Table 2-1-7.

2) Structural characteristics

(a) Lineaments and faults

The following three elements are enumerated as the morphological features used for identifying lineaments in the present area.

① Notably winding flow of rivers

② Notably linear flow of rivers

③ Linear pattern caused by tone difference

A total of 20 lineaments are extracted from this area.
Most of these lineaments are distributed in Unit Tvb1, Tvb2, and Unit A (alteration zone), and the length of lineaments are shorter than 3km.

(b) Folding
A gentle dipping anticline with axis extending in the NW-SE direction is inferred along the Quebrada Limpire (northern part of Cerro libunuma) from bedding trace on the Geoscan false color composite images.

(c) Annular structures, calderas and dome structures
From the morphology of ridges and existence of bedding planes on Geoscan false color composite images, development of volcanic rocks in this area is easily observed.

Many conic ridges like the Cerro Colorado mountain are observed, and the possibility of ridges being centers of the volcanic activities is high. In this part, lava dome is few although the stratovolcano and the dome type volcano is common.

Annular drainage system formed by the control of the volcanic activity is observed in Quebrada de Tana o Camina and its branches, and Quebrada Maimaja and its branches in the central part of this area. However, annular structure which originates in deep underground intrusive rocks is not seen in this area.

The sliding slope of a semicircle type is observed at the top of of the Cerro Guaichane mountain (4,686m above sea level) the highest peak in this area, and a small-scale depression structure is inferred there. It is thought that this phenomenon suggests the existence of the center of the volcanic activity. However, large scale caldera structures are not observed in this part.

3) Alteration zones
Alteration zones extracted from the Geoscan false color composite images exist widely in many places as shown in PL. 7-A.

The alteration zones (Unit A) are observed in Units Tva, Tvb1, and, Unit Tvc and are most abundant in Unit Tvb1, widely.

The upper part of the alteration zones in Unit Tvb1 distributed in the central part of this area is covered with a part of same Unit (Tvb1). The alteration zone extracted from Geoscan false color composite images shown in PL. 7-A occurs only as outcrop. However, most of these alteration zones are parts of the talus deposit (Unit Qtl), and are often covered with Qtl.

A close relationship between the distribution of lineaments and the alteration zones is not recognized. Photogeological characteristics of the alteration zones are shown in Table 2-1-5. The the alteration zones are divided into 25 groups by the resemblance of stratigraphy and distribution.

On the other hand, alteration zones extracted from the ratio images, the decorrelation stretched images (bands 12,13,14 and 14,15,16), and the thermal logarithmic residual image have similar distribution to those extracted from the false color composite images as shown in PL. 7-B.

Regarding the alteration minerals, sericite is commonly observed in this area, followed by smectite, kaolin-alunite and mixed layer clay minerals. Of these, in the kaolin-alunite zones observed in the central and southwestern parts, the characteristic greenish blue part suggesting the siliceous rock on the thermal logarithmic residual images is observed. Existence of kaolin-alunite shows the possibility that this greenish blue part corresponds to the silicified zone. These silicified alteration zones are observed in two places of the central part and a part of the southwestern part. Both of these occurrences are limited within areas smaller than 0.3km × 0.3km.

The alteration zones of this area are observed within the Units Tva, Tvb1, and Tvc where the relatively younger volcanic activity is dominant. Thus, the possibility of the alteration zones being observed in the younger geothermal region is noted.

(3) Mocha-Queen Elizabeth sub-area

1) Delineation of geologic units

The geologic units of this area are Jurassic volcanic and sedimentary rocks (Js1,Js1s), Cretaceous volcanic and sedimentary rocks (K1,K2), Tertiary pyroclastic rocks (Ti1, Ti2, Ti3, Ti4 and Ti4w), Quaternary unconsolidated sediments (Qal and Qtl) and the intrusive rocks (Kg, Kp, and d).

These units are distributed mainly as follows.
Qal : Along the main river
Qtl : Foot of mountain and or hills in the central to eastern part
Ti4 : Surroundings of mountainous part in the central to western part
Ti3 :Central to western part
Ti2 : Hillside of the western part
Ti1 : Same as above
K2 : Along river side of the northeastern part
K1 : Along river side of the eastern to western part
Js1 : Along river and hillside of the central part
Js1s : Top of a mountain part of the central part
Kp : Southeastern part (3km×3km+ α in scale)
Kg : Ravine portion of the southeastern part and along the river side of western part
d : Hillside of the eastern part

Characteristic and correlation of each unit with existing geologic maps are shown in Table 2-1-8.

2) Structural characteristics
(a) Lineaments and faults
The following four elements were enumerated as the morphological features used for identifying lineaments in the present area.

① Notably winding flow of rivers
② Linear continuation of break points of slopes
③ Notably linear flow of rivers
④ Linear pattern caused by tone difference

A total of 145 lineaments were extracted from this area. Most of these lineaments are distributed in Unit Kg, K1, Js1, and Js1s. Also four lineaments were extracted from Unit Ti4 and one from Unit Ti4s and six from Unit Tv.

The larger two lineaments are distributed in Tv, Qtl and Qal in the eastern part of the area. These two lineaments extend over 10km in the N-S～NNE-SSW directions respectively. Besides this, there are 13 lineaments (length; about 3-5km), and others about 0.5-2km long.

There are regional characteristics in the continuity of these lineaments. From the central to the eastern part, they are relatively continuous, but in the central to the western part, their continuity is poor. The western part is widely covered by Unit Ti3 and Ti4 from the central part and westward this is believed to be the reason for the above.

Regarding the direction of lineaments, NW-SE, NNE-SSW, and NE-SW systems are dominant. High lineament-density zones are observed comparatively often in the south-central part. Lineaments with poor continuity are developed in various directions.

(b) Folding

One anticlinal and two synclinal structures have been observed in Unit Js1 and Js1s in the central southern part. They both trend in the N-S direction.

(c) Annular structures, calderas and dome structures

Annular structure: An annular structure with 0.5km diameter is observed in Unit Kg in the northern part of this area. The tone of Unit Kg in this part is pale gray, which is different from other areas. An annular drainage system with slight depressions in the periphery is developed. This part is located in southeastern part of Mocha mineral showings, and corresponds to Soledad mineral showings.

Dome structure: The volcanic cone of about 3km×3km is observed in the southeastern part of this area. This corresponds to Unit Kp, and gentle topographic features compared with strata in the vicinity. This part corresponds to Queen Elizabeth mineral showings. Evidences of drilling exploration are clearly observed on the image.

3) Alteration zones

A total of 90 alteration zones were extracted from Geoscan false color images as shown in PL.8-A. Of these, 49 zones occur in Unit Kg, and 30 zones in Unit Js1. Other alteration zones observed are seven in Tv, two in Ti3, one in Js1s, and one in Ti4w.

High density parts of the alteration zones exist at the eastern part (No.1～3 ; three in Unit Tv, Kg and Js1), the central part (No.4～6 ; two in Unit Kg, one in Units Js1, Js1s and Kg) and the western part (No.7 ; one in Unit Kg).

The characteristics of these zones are as follows,

No 1; within 6.0×1.0km range, 3 Alteration zones, maximum size 2.0×0.8km
No 2; within 2.0×5.0km range, 11 Alteration zones, maximum size 0.6×0.3km
No 3; within 4.0×4.0km range, 11 Alteration zones, maximum size 1.8×0.3km
No 4; within 1.0×2.5km range, 3 Alteration zones, maximum size 0.8×0.8km
No 5; within 1.5×2.5km range, 14 Alteration zones, maximum scale 0.7×0.3km
No 6; within 4.0×3.5km range, 12 Alteration zones, maximum scale 0.7×0.3km
No 7; within 4.0×2.0km range, 15 Alteration zones, maximum scale 0.60×0.4km

Of these, No. 3 corresponds to Queen Elizabeth and No. 7 to Mocha prospects or its neighborhood.

On the other hand, the alteration zones extracted from the ratio images, the decorrelation stretched images (bands 12,13,14 and 14,15,16), and thermal logarithmic residual images occur in many localities other than those extracted from false color composite images as shown in PL.8-B.

Regarding the alteration minerals, sericite is observed in almost the whole area except an independent zone in the eastern part. Smectite is observed in central part, the central northern part, and the eastern part, and kaolin-alunite is observed in the eastern part.

Of these, the kaolin-alunite zone and the mixed-large argillized zone in the southwestern part contain the characteristic greenish blue parts indicating the existence of siliceous rocks on the thermal logarithmic residual images. Existence of kaolin-alunite indicates the possibility that this greenish blue parts corresponds to silicified zones.

Close relationship between the distribution of lineaments and the alteration zones is not recognized.

(4) Cerro Colorado sub-area

1) Delineation of geologic units

Geologic units of this area are Cretaceous volcanic rocks (K1), Tertiary volcanic pyroclastic rocks (Ti3 and Ti4), Quaternary unconsolidated sediments (Qal) and the Late Cretaceous to Palrogene intrusive rocks (Kg).

These units are mainly distributed as follows.

Qal : Along the main river

Ti4 : Mainly eastern part, (topographically upper part of unit Ti3)

Ti3 : Westernmost, northern-central part and southeastern part

K1 : Central part

Kg : Isolated distribution as six bodies.

Northwestern part ; about 2km × 3km in size

Central and southwesternmost part ; about 3km × 1.5km in size

Central eastern part ; about 0.2km × 0.2km and 0.5km × 0.5km in size

Central of the western part ; about 0.5km × 0.5km in size

Characteristic correlation of each unit and with existing geologic maps are shown in Table 2-1-9.

2) Structural characteristics

(a) Lineaments and faults

The following three elements are enumerated as the morphological features used for identifying lineaments in the present area.

① Notably winding flow of rivers

② Linear continuation of break points of slopes

③ Notably linear flow of rivers

A total of 52 lineaments were extracted from this area

Most of these lineaments are observed in the center part of Units K1 and Kg. The largest lineament observed in the southwestern part of Units K1 and Ti4 is continuous for about 2.5km in the NE-SW direction.

Regarding direction of lineaments, NNW-SSE, N-S, and NW-SE systems are dominant in this area. Besides this, there are five lineaments extending in the E-W direction in the central part.

(b) Folding

Folding is not observed in this area.

(c) Annular structures, calderas, and dome structures

Annular structures, calderas and dome structures are not observed in this area.

3) Alteration zones

A total of 51 alteration zones were extracted from Geoscan false color images as shown in PL. 9-A. Of these, 46 zones are observed in Unit Kl, and five in Unit Ti3.

High-density part of alteration zones are generally observed in the following four places.

① The northwestern part (2 alteration zones; maximum 0.6km×0.1km in size)

② Center part (21 alteration zones; maximum 0.2km×0.2km in size)

③ Eastern part (23 alteration zones; maximum 0.9 km×0.5km in size)

④ Southwestern part (5 alteration zones; maximum 0.2km×0.1km in size)

On the other hand, alteration zones extracted from ratio images, the decorrelation stretched images (bands, 12,13,14 and 14,15,16), and thermal logarithmic residual images have similar distribution to those extracted from the false color composite image as shown in PL.9-B.

Regarding alteration minerals, sericite is commonly observed, kaolin-alunite is observed at two places in the sericite zone in the eastern part. Of these, the kaolin-alunite zone contain the characteristic greenish blue parts indicating the existence of siliceous rocks on the thermal logarithmic residual images. Existence of kaolin-alunite shows the possibility that this greenish blue part corresponds to the silicified zone.

High lineament-density regions and high density regions of alteration zones are harmonious well.

(5) Copaquiri sub-area

1) Delineation of geologic units

The geologic units of this area are of Paleozoic semi-schists (Unit : Pz), Jurassic sedimentary rocks (Unit : Js1 and Js2), Cretaceous volcanic rocks (Unit :K1), Tertiary sedimentary rocks (Unit : Tt) , Quaternary unconsolidated sediments (unit : Qal) and the Paleozoic to Tertiary intrusive rocks (Unit : Pzg, Kg, Tgd, and Tg).

These units are mainly distributed as follows.

Qal : Along the main river

Tt : Mainly eastern part
Kl : western most , central northern part, and the southeastern part
Js1 : Southern central part
Js2 : Mostly of Whole area (except other units)
Pz : Southeastern part, width of about 5.5km and direction of NNE-SSW
Tg : Isolated as seven bodies, and direction of N-S to NNE-SSW
maximum 3.5km × 12km in scale and distributed in northern central part
Tgd : 7km × 1.2km in scale with ENE-WSW direction, distributed in the northwestern part.
Kg : 3km width, with N-S direction, distributed in the eastern part
Pzg : Isolated as three bodies (each 4km × 7km, 2km × 1.2km and 0.5km × 0.5km in scale)

Characteristic and correlation of each unit with existing geologic maps are shown in Table 2-1-10.

2) Structural characteristics

(a) Lineaments and faults

The following five elements are enumerated as the morphological features used for identifying lineaments in the present area.

① Notably winding flow of rivers
② Linear continuation of break points of slopes
③ Notably linear flow of rivers
④ Straight line and wide valley
⑤ Existence of topographical features which extend side by side with specific direction

A total of 86 lineaments were extracted from this area.
These lineaments can be generally grouped into the following six high lineament-density localities. Lineaments of the E-W system are relatively continuous.

(i) Eastern part (total of 29 lineaments. NNW-SSE and NW-SE system is dominant with maximum length of 6.5km.)
(ii) Central part (total of 27 lineaments. NW-SE, E-W and NNE-SSW system are dominant with maximum length of 6.5km.)
(iii) Southwestern part (total of 11 lineaments. WNW-ESE system is dominant with

maximum length of 1.5km.)

(iv) Southwestern part (total of 8 lineaments. NNW-SSE system is dominant with maximum length of 1.0km.)

(v) Southern central part (total of 7 lineaments. NNE-SSW system is dominant with maximum length of 0.6km.)

(vi) Southeasternmost part (total of 4 lineaments. Only NE-SW system is observed with maximum length of 0.5km.)

(b) Folding

Folding is not observed in this area.

(c) Annular structures, calderas, and dome structures

Annular structures, calderas and dome structures are not observed in this area.

3) Alteration zones

A total of 104 alteration zones were extracted from Geoscan false color image as shown in PL.10-A. These alteration zones extend almost parallel in the N-S direction, and are roughly divided into the following six high distribution-density zone.

(i) Eastern part (12km × 5km, total of 37 zones, maximum size 0.8km × 0.2km)

(ii) Western part (15km × 6km, total of 41 zones, maximum size 0.7km × 0.4km)

(iii) Northwestern part (2.5km × 1km, total of 6 zones, maximum size 0.4km × 0.1km)

(iv) Southeastern part (6.5km × 1.5km, total of 11 zones, maximum size 1.1km × 0.5km)

(v) Southeasternmost part (2.5km × 1.5km, total of 2 zones, maximum size0.4km × 0.1km)

(vi) Southwesternmost part (3.3km × 5km, total of 7 zones, maximum size 3.0km × 0.8km)

On the other hand, alteration zones extracted from ratio images, the decorrelation stretched images (bands, 12,13,14 and 14,15,16), and thermal logarithmic residual images have similar distribution to those extracted from the false color composite images as shown in PL.10-B. However, alteration zones were not extracted on false color composite images within smectite zones and sericite zones in the center of the northern part and the southeasternmost part.

Regarding the alteration mineral sericite is commonly observed, mixed layer clay mineral is observed in the western central part and the northeastern part, smectite is observed in the eastern part and the southern part, kaolin-alunite is observed in the western central part.

Of these, the kaolin-alunite zones contain characteristic greenish blue parts indicating the existence of siliceous rocks on the thermal logarithmic residual images. Existence of kaolin-alunite shows the possibility that this greenish blue part corresponds to silicified zone.

A high lineament-density zone and a high density zone of alteration zone harmonize well.

(6) Collahuasi sub-area

1) Delineation of geologic units

The geologic units of this area are Paleozoic semi-schists (Unit : Pz), Jurassic sedimentary rocks (Unit : Jkv), Quaternary unconsolidated sediments (unit : Qal) and the Cretaceous to Tertiary intrusive rocks (Unit : Kg, and Tg).

These units are mainly distributed as follows.

Qal : Along the main river

Jkv : Mainly eastern part, scattered in seven places

Pz : Almost whole area

Tg : Isolated as two bodies in northern central part, size of 0.4km × 0.4km

Kg : Southern part and central part, isolated as three bodies in the central part, maximum size of 2km × 1.5km

Characteristic and correlation of each unit with an existing geologic maps are shown in Table 2-1-11.

2) Structural characteristics

(a) Lineaments and faults

The following four elements are enumerated as the morphological features used for identifying lineaments in the present area.

① Notably winding flow of rivers

② Linear continuation of break points of slopes

③ Notably linear flow of rivers

④ Existence of topographical features which runs side by side with specific direction

A total of 42 lineaments were extracted from this area.
Regarding the direction of lineaments, the NNE-SSW and the NE-SE systems are dominant. The longest lineament is over 8 km in the NNE-SSW system and 4.5 km in the NW-SE system. Other lineaments are relatively continuous with length of 2～3km.

(b) Folding
Folding is not observed in this area.

(c) Annular structures, calderas, and dome structures
Annular structures, calderas and dome structures are not observed in this area.

3) Alteration zones
A total of 8 alteration zones were extracted in the central part from Geoscan false color images as shown in PL. 11-A. These zones occur within a range of 4.5km×4.5km. The largest alteration zone is about 2.5km×1.5km, following by a 3.0km×0.7km zone.

On the other hand, the alteration zones extracted from the ratio image, the decorrelation stretched image (bands 12,13,14 and 14,15,16), and the thermal logarithmic residual image occur in many localities other than those extracted from the false color composite image as shown in PL.11-B. However, these consist mostly of smectite, and neither sericite nor kaolin-alunite is observed.

Regarding the alteration mineral, sericite, smectite and kaolin-alunite are observed. Of these, in the kaolin-alunite zone, characteristic greenish blue part suggesting the siliceous rock on the thermal logarithmic residual image is observed. Existence of kaolin-alunite shows the possibility that this greenish blue part corresponds to the silicified zone.

High lineament-density regions and high density region of alteration zones are harmonious well.

Table 2-1-5 Photogeological Interpretaiton of Geoscan Images (1)

Area (Name of Image)	Number of Potogeologic Unit	Kind of Image	Alteration zone: Number	Alteration zone: Wall Rock Formation	Alteration zone: Arrangement Direction	Alteration zone: Shape (extension direction)	Alteration zone: Size (km× km)	Alteration zone: Alteration Minerals	Lineament: Number	Lineament: Wall Rock Formation	Lineament: Direction	Lineament: Length (km)	Lineament: Direction of Lineament near Alteration Zone	Folding / Annular structure
① Tignamar	8 Paleoz. sed: : 1 C-T, volc : 1 Ter, Int : 1 Ter, Volc : 1 T-Q, volc : 1 Q, sed : 1 Alt. Z : 1	F	53	C-T. volc T-Q. volc		elliptic irregular N-S	max. 1.9×0.3, 1.0+×0.5		58	Paleoz. Sed C-T. volc Ter. int T-Q. volc Q. sed	N-S NW-SE WNW-ESE	0.3～8.0	WNW-ESE N-S	Annular str. K2, φ1.0km
		RI DS TLR	69				max. 3.1×2.7	Ser Alu-Kao Smec Sili						
② Palca	8 T-Q, volc : 3 Q, sed : 4 Alt. Z : 1	F	153	T-Q. volc	N-S	elliptic irregular NW-SE	max. 6.1×2.7		18	T-Q. volc	N-S NW-SE NNW-SSE (NNE-SSW)	0.4～2.2	N-S NW-SE NNW-SSE (NNE-SSW)	Anticlinal str. with NW-SE axis in Tv
		RI DS TLR	130			elliptic, irregular N-S,E-W NW-SE	max. 5.4×3.4	Ser Smec Alu-Kao Sili						
③ Mocha-Queen Elizabeth	17 C-T, int 3 Jur. Sed, volc : 2 Cret, sed : 1 Cret, volc : 1 Ter, vol : 6 Q, sed : 2 d. : 1 Alt. Z : 1	F	90	Jur. sed Cret. volc C-T. volc C-T. int Ter. volc T-Q volc	N-S	elliptic irregular N-S NW-SE (NW-SE)	max. 1.8×0.7		145	Jur. sed Cret. volc Cret. int Ter. volc T-Q. volc d	NW-SE N-S NNE-SSW NE-SW	0.2～11	NW-SE N-S	Annular str. Kg, φ0.5km Anticlinal str. with N-S axis in Js1 & Js1s Synclinal str. with N-S axis in Js1 & Js1s×2
		RI DS TLR	275		N-S NW-SE NE-SW	elliptic, irregular N-S NW-SE NE-SW, E-W	max. 3.1×1.9	Ser Smec Alu-Kao Sili mixed						

Table 2-1-5 Photogeological Interpretaiton of Geoscan Images (2)

Area (Name of Image)	Number of Potogeologic Unit	Kind of Image	Alteration zone: Number	Alteration zone: Wall Rock Formation	Alteration zone: Arrangement Direction	Alteration zone: Shape (extension direction)	Alteration zone: Size (km× km)	Alteration zone: Alteration Minerals	Lineament: Number	Lineament: Wall Rock Formation	Lineament: Direction	Lineament: Length (km)	Lineament: Direction of Lineament near Alteration Zone	Folding / Annular structure
④ Cerro Colorado	6 Cret., Int/volc 2 T-Q, volc/sed: 2 Q, sed: 1 Alt. Z: 1	F	54	Cret. Int Cret. volc T-Q. sed	NNW-SSE N-S E-W	elliptic, irregular NNW-SSE, N-S, (E-W)	max. 0.9×0.6		52	Cret. int Cret. volc T-Q. sed Q. sed	N-S NW-SE ENE-WSW (NE-SW)	0.2～2.6	N-S NNW-SSE NW-SE (NE-SW)	none
		RI DS TLR	67		NNW-SSE E-W	elliptic, irregular NNW-SSE, N-S, (E-W)	max. 1.3×1.1, 1.7×0.9	Ser Alu-Kao Sili						
⑤ Copaqiuri	11 Paleoz, int: 1 Paleoz, sed : Jur, sed : 2 C-T, volc : 1 Ter, int : 2 Ter, volc : 1 Q, sed : 1 dyke, : 1 Alt. z, : 1	F	104	Paleoz . int: Paleoz. sed Jur. sed Cret. int Ter. int Ter. volc	N-S NW-SE E-W	N-S NNW-SSE, N-S (E-W) NNE-SSW E-W, N-S, NW-SE, NE-SW E-W	max. 2.9×0.8 max. 9.0×5.0		86	Paleoz. int Paleoz. sed Jur. sed Cret. int Ter. int Ter. volc Q. sed	N-S NW-SE NE-SW E-W NNE-SSW	0.3～7.5	NW-SE N-S NE-SW	none
		RI DS TLR	107					Ser, Smec, Alu-Kao, Sili, mixed						
⑥ Collahuasi	6 C-T. int: 1 Jur. sed: 1 C-T. int: 1 Ter. int: 1 Q. sed: 1 Alt. Z 1	F	12	C-T. int Jur. sed C-T. int:	N-S	irregular	max. 2.2×1.7		42	C-T. int Jur. sed C-T. int: Q. sed:	N-S NNW-SSE NW-SE NNE-SSW	0.7～7.7	NW-SE NNE-SSW N-E	none
		RI DS TLR	30			elliptic, irregular N-S NW-SE	max. 4.5+× 3.5+	Ser Smec Alu-Kao Sili						

RI : Ratio Image, DS : Decorrelation Stretched Image, TLR : Thermal Logarithmic Residual Image

Abbrev. P=Paleozoic, J=Jurassic, Cret=Cretaceous, T=tertiary, Q-quaternary, A=Alteration, volc=volcanics, sed=sedimentary rocks, int=intrusive, gr=granitic rock, str=structure, Alt. Z =Alteration Zone

Table 2-1-6 Characteristics of Photogeologic Units of the Tignamar Area

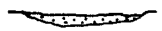
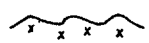
Unit	Photo-Characteristics		Mophologic Expression					Superficial Cover		Probable Lithology
	Tone	Texture	Drainage		Rock	Section	Bedding	Vegetation	Cultivation	(Correlation with available Geologic Map)
			Pattern	Density	Resistance					
Qal	pale brown	very fine	meandering	very low	very low		none	partly	partly	Unconsolidated sediments composed of gravel, sand, silt and clay (Alluvium)
Qtl	pale brown	fine	parallel	low	low		none	none	none	Talus deposits
Ti_4	pale brown	medium	sub-dendritic	medium	high~medium		very gentle	none	none	Sedimentary rocks Imagua member : (Pliocene to Pleistocene : Sandstone and conglomerate)
Ti_3	gray	rough	parallel	low~medium	high~medium		very gentle	none	none	Pyroclastic rocks (Pliocene to Pleistocene : Tombillo member : Ignimbrite)
K_2	blueish gray	medium	parallel	medium	medium		partly	none	none	Volcanic rocks (Late Cretaceous to Early Tertiary : Rhyolitic to dacitic lava and tuffs)
Pz	brown	coarse	sub-parallel	high	medium		unknown	none	none	Meta Sedimentary rocks and volcanic rocks (Carboniferous to Permian : Collahuasi Formation, Micaceous schist, gneiss, phyllite, quartzite intercalated with dacitic to andesitic volcanic rocks)
Tgd	gray	rough	sub-rectangular	medium	high		none	none	none	Igneous rocks (Tertiary : Quartz diorite)
A	light gray	fine	sub-dendritic	low	low		none	none	none	Alteration Zone (Hydrothermal alteration zone)

Table 2-1-7 Characteristics of Photogeologic Units of the Palca Area

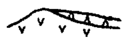
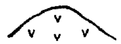
Unit	Photo-Characteristics		Mophologic Expression					Superficial Cover		Probable Lithology
	Tone	Texture	Drainage		Rock	Section	Bedding	Vegetation	Cultivation	(Correlation with available Geologic Map)
			Pattern	Density	Resistance					
Qal	white, light gray	very fine	meandering	low	very low		none	partly	none	Unconsolidated sediments composed of gravel, sand, silt and clay (Alluvium)
Qti	white, gray	very fine	sub-parallel, distributary	high	very low		rare	none	none	Talus deposits
Qf	blueish gray	fine	distributary	medium	very low		rare	none	none	Fan deposits
Qs	blueish gray	fine	sub-parallel	low	low		none	none	none	Unconsolidated sediments composed of gravel and sand
Tvc	brown	medium	radial	medium	very high		none	none	none	Volcanic rocks composed of lavas and pyroclastic rocks (Pliocene to Pleistocene : Andesitic to basaltic flow with pyroclastic rocks)
Tvb_2	light blue	medium	sub-parallel	low	medium~low		rare	none	none	Ignimbrite (Pliocene to Pleistocene : Andesitic to basaltic flow with pyroclastic rocks)
Tvb_1	brown	coarse	dendritic, radial	high	medium~very high		partly bedded	none	none	Volcanic rocks composed of lavas and pyroclastic rocks (Pliocene to Pleistocene : Andesitic to basaltic flow with pyroclastic rocks)
Tva	brown, purplish gray	fine~ medium	radial	medium	very high		none	none	none	Volcanic rocks (Pliocene to Pleistocene : Andesitic to basaltic flow with pyroclastic rocks)
A	white, dark greenish gray	fine	sub-dendritic	medium	low		none	none	none	Alteration Zone (Hydrothermal alteration zone)

Table 2-1-8 Characteristics of Photogeological Units of the Mocha- Queen Elizabeth Area (1)

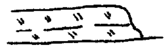
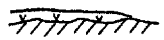
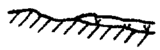
Unit	Photo-Characteristics		Mophologic Expression					Superficial Cover		Probable Lithology
	Tone	Texture	Drainage		Rock	Section	Bedding	Vegetation	Cultivation	(Correlation with available Geologic Map)
			Pattern	Density	Resistance					
Qal	pale brown	very fine	meandering	very low	very low		none	partly	partly	Unconsolidated sediments composed of gravel, sand, silt and clay (Alluvium)
Qtl	pale brown	fine~ medium	sub-parallel	low	low		none	none	none	Talus deposits
Ti_{4w}	light gray	fine	sub-dendritic	low~medium	medium		very gentle	none	none	Pyroclastic rocks (Pliocene to Pleistocene : Ignimbrite)
Ti_4	brownish gray	fine	sub-parallel	medium~high	medium		very gentle	none	none	Pyroclastic rocks (Pliocene to Pleistocene : Ignimbrite)
Ti_3	dark gray, blueish gray	fine	sub-parallel	medium	low~medium		very gentle	none	none	Pyroclastic rocks (Pliocene to Pleistocene : Ignimbrite)
Ti_2	light gray	fine	sub-dendritic	medium	low~medium		very gentle	none	none	Pyroclastic rocks (Pliocene to Pleistocene : Ignimbrite)
Ti_1	gray, light gray	fine	sub-dendritic	medium	medium		very gentle	none	none	Pyroclastic rocks (Pliocene to Pleistocene : Ignimbrite)
Tv	dark brown	medium~ coarse	sub-parallel	medium	medium~high		partly	shrubs	none	Volcanic rocs (Pliocene to Pleistocene : andesitic basaltic breccia intercalated with sedimentary rocks
K_2	greenish brown	coarse	sub-dendritic	medium	medium~high		partly	none	none	Sedimentary and pyroclastic rocks (Early Cretaceous to Late Tertiary : shale, limestone, sandstone, conglomerate and pyroclastic rocks
K_1	purplish brown	coarse~ medium	sub-parallel	medium~high	medium~high		partly	none	none	Pyroclastics and sedimentary rocks (Early Cretaceous : andesitic to rhyolitic tuffs, trachytic tuffs and ignimbrite intercalated with sedimentary rocks
Js_1	blueish gray	medium	sub-dendritic	medium	medium		partly	none	none	Volcanic rocks and sedimentary rocks (Dogger~Malm : Andesitic to rhyolitic volcanic rocks intercalated with sedimentary rocks

Table 2-1-8 Characteristics of Photogeological Units of the Mocha- Queen Elizabeth Area (2)

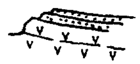
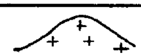
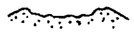
Unit	Photo-Characteristics		Mophologic Expression					Superficial Cover		Probable Lithology
	Tone	Texture	Drainage		Rock	Section	Bedding	Vegetation	Cultivation	(Correlation with available Geologic Map)
			Pattern	Density	Resistance					
Js_{1a}	greenish brown, light gray	medium	sub-parallel	medium~high	medium~high		well bedded	shrubs	none	Sedimentary rocks and volcanic rocks (Dogger~Malm : Sandstone, calcareous sandstone, limestone, shale, dolomite intercalated with andesitic to rhyolitic volcanic rocks)
Kp	dark gray	fine~ medium	sub-parallel	low	medium~high		none	none	none	Igneous rocks (Cretaceous : Quartz porphyry)
Kg	blueish gray	medium~ coarse	sub-parallel, rectangular	high	medium~high		none	none	none	Igneous rocks (Late Jurassic to Early Cretaceous : Plutonic rocks and Hypabyssal rocks)
d	greenish gray	rough	sub-parallel	medium	high		none	shrubs	none	Dyke rocks
A	light gray	fine	sub-dendritic	low	low		none	none	none	Alteration Zone (Hydrothermal alteration zone)

Table 2-1-9 Characteristics of Photogeologic Units of the Cerro Colorado Area

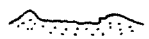
Unit	Photo-Characteristics		Mopholgic Expression					Superficial Cover		Probable Lithology
	Tone	Texture	Drainage		Rock	Section	Bedding	Vegetation	Cultivation	(Correlation with available Geologic Map)
			Pattern	Density	Resistance					
Qal	pale brown	very fine	meandering	very low	very low		none	partly	partly	Unconsolidated sediments composed of gravel, sand, silt and clay (Alluvium)
Ti_4	brown	fine~medium	pinnet, sub-parallel	medium	medium		very gentle	none	none	Sedimentary rocks Imagua member : (Pliocene to Pleistocene : Sandstone and conglomerate)
Ti_3	blueish gray	fine~medium	sub-parallel	medium	medium		very gentle	none	none	Pyroclastic rocks (Pliocene to Pleistocene : Tombillo member : Ignimbrite)
K_1	brownish green	coarse	sub-parallel	medium~high	medium~high		partly	none	none	Volcanic rocks (Barriasian to Santonian : Cerro Empexa Formation : Andesitic breccia, trachyte, latite, tuff and conglomerate)
Kg	greenish gray	medium	sub-rectangular	medium	high		none	none	none	Igneous rocks (Late cretaceous : Granite, granodiorite, adamellite and tonalite)
A	light gray	fine	sub-dendritic	low	low		none	none	none	Alteration Zone (Hydrothermal alteration zone)

Table 2-1-10 Characteristics of Photogeologic Units of the Copaquiri Area

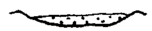
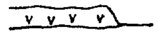
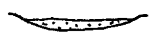
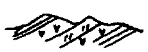
Unit	Photo-Characteristics		Mophologic Expression					Superficial Cover		Probable Lithology
	Tone	Texture	Drainage		Rock	Section	Bedding	Vegetation	Cultivation	(Correlation with available Geologic Map)
			Pattern	Density	Resistance					
Qal	pale brown	very fine	meandering	very low	very low		none	partly	partly	Unconsolidated sediments composed of gravel, sand, silt and clay (Alluvium)
Tt	moss green	fine	sub-parallel	low	low~medium		very gentle	none	none	Sedimentary rocks (Upper Miocene to Pliocene : Breccias, conglomerate, sandstone and dacitic tuffs)
K_1	brown, green	fine~meium	parallel	medium	medium		partly	none	none	Volcanic rocks (Tithonian to Late Cretaceous : Cerro Empexa Formation, Andesite with andesitic tuffs and dacitic tuffs)
Js_2	blueish green	fine~meium	sub-dendritic	medium~high	medium		rare	none	none	Sedimentary rocks (Colovian to Kimmeridgean : Quehuita Formation, Sandstone, shale and conglomerate)
Js_1	pale purple	medium	sub-parallel	medium	medium		partly	none	none	Sedimentary rocks (Colovian to Kimmeridgean : Quehuita Formation, Conglomerate, calcareous sandstone, shale with limestone
Pz	purplish brown	coarse	sub-parallel	high	medium~high		unknown	none	none	Meta Sedimentary rocks and volcanic rocks (Carboniferous to Permian : Collahuasi Formation, Micaceous schist, gneiss, phyllite, quartzite intercalated with dacitic to andesitic volcanic rocks)
Tg	gray	medium	sub-rectangular	medium	high		none	none	none	Igneous rocks (Tertiary : Granoodiorite)
Tgd	light gray	medium	sub-dendritic	medium	high		none	none	none	Igneous rocks (Tertiary : Quartz diorite)
Kg	light gray	medium	sub-rectangular	medium	high		none	none	none	Igneous rocks (Cretaceous : Quartz diorite porphyry)
Pzg	gray	rough~coarse	sub-rectangular	medium	high		none	none	none	Igneous rocks (Paleozoic : Granitic rocks)
d	dark brown	rough	sub-parallel	medium	high		none	none	none	Dyke rocks
A	light gray	fine	sub-dendritic	low	low		none	none	none	Alteration Zone (Hydrothermal alteration zone)

Table 2-1-11 Characteristics of Photogeologic Units of the Collahuasi Area

Unit	Photo-Characteristics		Mophologic Expression					Superficial Cover		Probable Lithology
	Tone	Texture	Drainage		Rock	Section	Bedding	Vegetation	Cultivation	(Correlation with available Geologic Map)
			Pattern	Density	Resistance					
Qal	pale brown	very fine	meandering	very low	very low		none	partly	partly	Unconsolidated sediments composed of gravel, sand, silt and clay (Alluvium)
Jkv	brown	coarse	sub-parallel	medium	medium		rare	none	none	Volcanic and sedimentary rocks (Late Jurassic to Early Cretaceous : Basalt lava , doleritic dikes, trachyte with tuffs and chert)
Pzv	brown	rough	sub-dendritic	high	medium~high		rare	none	none	Meta-volcanic rocks (Carboniferous to Permian : Collahuasi Formation,Dacitic to andesitic volcanic rocks)
Pz	blueish gray	fine	sub-parallel	medium	medium~high		none	none	none	Meta Sedimentary rocks and volcanic rocks (Carboniferous to Permian : Collahuasi Formation, Micaceous schist, gneiss, phyllite, quartzite intercalated with dacitic to andesitic volcanic rocks)
Kg	pale gray	rough	sub-rectangular	medium~high	medium~high		none	none	none	Igneous rocks (Cretaceous : Granite porphyry)
A	light gray	fine	sub-dendritic	low	low		none	none	none	Alteration Zone (Hydrothermal alteration zone)