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PLUTONICS NEAR AREQUIPA AS A PETROLOGIC SAMPLE OF THE COASTAL BATHOLITH IN PERU

by WILLIAM F. JENKS and ELLWOOD G. HARRIS

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Extracto

La parte sur-occidental de la hoja de Arequipa, está ocupada por rocas plutónicas, las que constituyen alrededor del 2.6% del área del batolito costanero peruano. El batolito es complejo y se conocen cuando menos cinco distintos períodos de intrusión. El primer cuerpo intrusivo, constituído principalmente de tonalita, es altamente gneisico y muestra fuerte textura cataclástica. Las variaciones en los tres primeros grupos intrusivos abarcan desde gabro hasta granito, sin embargo la roca más abundante es tonalita, la que está ampliamente distribuída en los Cerros de la Caldera. Una cuarta unidad intrusiva, que corta claramente a las anteriores está constituída por granodiorita y tonalita de grano grueso, habiendo sido analizada químicamente una muestra de ella. Ocupa un área de 55 km. cuadrados. Las variaciones de textura y composición en esta roca no son grandes y su composición promedio es de granodiorita cercana a tonalita.

Las intrusiones finales de las series batolíticas son stocks pequeños de granito de grano fino, pero no se manifiesta una ordenada progresión de las rocas básicas a las ácidas, en esta parte del batolito. El batolito costanero del Perú es en varios modos comparable al del Sur de California.

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Abstract:

The southwest part of Arequipa quadrangle, southern Peru, is underlain by plutonic rocks which make up about 2.6% by area of the coastal batholith in Peru. The batholith is complex and at least five surges of intrusion are known to have ocurred. The earliest intrusive body, made up largely of tonalite, is gneissic throughout and shows strong cataclastic texture. Variations in the first three groups of intrusions range from gabbro to granite, but the most abundant rock is tonalite, which is widely distributed through the Cerros de la Caldera. A fourth intrusive unit, clearly cutting the earlier ones, is a medium to coarse grained granodiorite and tonalite a sample of which has been chemically analysed. It underlies an area of 55 square kilometers. Variations in texture and composition of this rock are not great, and its average composition is a granodiorite near tonalite.

The final intrusives of the batholithic series are small stocks of fine grained granite, but no orderly progression from basic to acid rocks is evident in this part of the batholith. The coastal batholith of Peru is comparable in many ways to that of southern California.

GENERALITY

In Peru the coastal batholith is extensively developed. From Chiclayo in the northwest to Ocoña in the southeast the plutonic rocks are nearly continuous and form a broad band. From Ocoña southeastward the batholith is more irregular and is farther inland. The batholith may be thought of as continuing in depth without interruption throughout this distance of some 1700 kilometers . As is shown on the Geologic Map of South America the batholith in places is more than 75 kilometers wide. If it were not for the overlap of Tertiary marine and continental sediments from the west, and of Tertiary and later volcanic rocks from the east, the width of the batholith would be more consistent, and the connection between various apparently isolated portions of the batholith would be more obvious.

The batholith along the northwest-trending part of the Peruvian coast occupies an area of aproximately 35,000 square kilometers. This figure includes portions of the batholith beneath Tertiary and later formations, but excludes other batholiths separated from the principal mass and located farther east in the Andes proper.

The Arequipa quadrangle (1) includes a small portion of the coastal batholith, which cuts across the southwestern part of the quadrangle and forms the bulk of the Cerros de la Caldera southwest and west of Arequipa. It is exposed in an area of about 1,500 square kilometers within the quadrangle, and in all probability is thinly covered by volcanic or sedimentary rocks in an additional 700 square kilometers. The plutonics in the area studied represent about 2.6% of the estimated total area of the batholith in Peru.

The sampling of the plutonic rocks was influenced by the convenience and exigencies of field work. The report published in 1948 by Jenks was based wholly on field identification of rock type using such criteria as color, texture, and presence or absence of recognizable quartz, potash feldspar, plagioclase, biotite, hornblende, or augite. Certain of the rock bodies appear to be fairly uniform and could reasonably be considered as essentially homogeneous units of the composite coastal batholith.

In the Arequipa area the batholith is far more complex than in places where it is broader and less broken up by roof pendants. In the Rimac Valley, for example, the uniformity of the coarse granodiorite is striking, as it is also along the Pan-American Highway as far north as Trujillo. In those areas the batholith is broad and the upper portions have been deeply eroded. Near Arequipa, on the other hand, the present erosion surface is not much below the original upper limit or roof of the intrusive. Evidence for this is the presence of large roof pendants in the Arequipa area, and the diminishing size of exposed intrusive areas southeastward toward Moquegua.

Jenks (1948, p. 63, 165) separated the intrusives and related phenomena into the following five successive stages:

Stage 1. Coarse grained granites, granodiorites and probably diorites, usually foliated

Stage 2. Augite diorite

Stage 3. Granodiorite and probably granite

(1) Hoja 17e of the Carta Nacional, published in 1940 by the Servicio Geográfico del Ejército.

Stage 4. Quartz diorite, hornblende diorite, quartz monzonite, and syenite
Stage. 5 Granite and quartz porphyry

HUASAMAYO TONALITE

The rocks which Jenks (1948) considered as representing the oldest part of the batholith are located on and near Cerro Huasamayo, in the part of the Cerros de la Caldera east of Vitor and largely south of the Rio de Vitor. Originally called granites, granodiorites and probably diorites of the earliest intrusive stage, these rocks may more exactly be termed the Huasamayo tonalite (2). Microscopic examination shows that the most characteristic rock of this early stage is tonalite. Variations range from granodiorite in the north to quartz monzonite in the south.

The tonalite is medium to coarse grained, with grains from 5 to 8 mm. (or rarely 10) in diameter. In most specimens biotite is in elongated streaks which, together with a gross banding of dark and light minerals, gives the rock a gneissic appearance. A modal analysis of the tonalite is given in Table 1, column 1. The plagioclase is andesine (average An37; range An32 to An47) which is moderately zoned. The quartz shows a high degree of strain in most thin sections examined. Much of the quartz occurs in clusters of small interlocking grains, probably the result of granulation. Biotite appears to be largely an alteration of hornblende. In the most strongly metamorphosed samples the biotite is crushed and molded around large quartz and feldspar grains.

Accessory minerals which have been observed are magnetite, apatite, sphene, zircon, hematite, tourmaline, epidote, and calcite.

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(2) Nomenclature in this paper follows WAHLSTROM (1947, p. 265-266).

TABLE 1

Modes (approximate weight percent) of representative rocks of the Huasamayo tonalite and Tingo complex, Arequipa quadrangle

	1	2	3	4	5
Quartz	31	36	40	2	24
K-feldspar	12	18	31	0.5	30
Plagioclase	48	31	24	45.5	37
Hornblende	7	—	—	45	6
Biotite	1	11	4	—	2
Accessories	1	4	1	7	1
Total	100	100	100	100.0	100

1. Huasamayo tonalite (AR385). Slope one km. NW of junction of Yura and Chili Rivers. Accessories are epidote, zircon, apatite, magnetite, and calcite.
2. Granodiorite phase of Huasamayo tonalite (AR247). Ridge NW of Yura River, 4 km. NE of junction Chili River. Accessories are epidote, hematite, magnetite, and apatite.
3. Quartz monzonite phase of Huasamayo tonalite (AR250). Railway cut at pass between Vitor and Quishuarani. Accessories are magnetite ,epidote, muscovite, and tourmaline.
4. Diorite of Tingo complex (AR84). Hill 2 km. NE of Tiabaya. Accesories are magnetite (6.6%), apatite, and calcite.
5. Granodiorite of Tingo complex (AR83). Hill at Sachaca. Accessories are magnetite, epidote, zircon, and apatite.

Variations from the average composition of the Huasamayo tonalite are illustrated by modal analyses numbers 2 and 3 in Table 1. Each of these rocks shows the effects of crushing and shearing, though the quartz monzonite does not appear so sheared in hand specimen because of the paucity of dark minerals.

TINGO COMPLEX

Jenks' second stage of intrusion, augite diorite, was named from Douglas' original petrographic descriptions (1920, p. 24).

The rocks in the vicinity of Huaico, Tingo, Tiabaya, and Socabaya are, however, of many different types, though they all seem to be related. The zone should be studied in detail to work out relationships of the various intrusive types. Most of the zone shows the effects of hydrothermal alteration, and many of the thin sections show such alteration that modal analysis gives little idea of the composition of the original rock. Columns 4 and 5 represent the range of varieties among the specimens collected by the senior author. In none of the specimens was augite detected, though some of the hornblende may have been derived from pyroxene. Douglas (1920, p. 24) noted augite in various stages of conversion to amphiboles.

Intense epidotization characterizes many of the rocks of the Tingo complex. Epidote appears to be of two types, of deuteric and hydrothermal origin. The deuteric epidote, rather uniformly disseminated through the rocks, is generally associated with the ferromaguesian minerals and apparently was produced by reaction involving the latter minerals. Hydrothermal epidote is clearly recognized where veins of nearly pure epidote transect the rocks. Careful inspection shows that a gradational border of diorite or other rock partly replaced by epidote and chlorite is common. More diffuse dissemination of epidote in epidote-rich rocks my be due either to deuteric or hydrothermal processes.

The two types of epidote (both with the general optical properties of pistacite) may be distinguished because the deuteric epidote is in general more strongly pleochroic and has a more pronounced lemon green color in thin section than that of hydrothermal origin. It is possible that the deuteric epidote has a higher ferric iron content than the other.

CALDERA INTRUSIVES

The largest portion of the batholith within the Arequipa quadrangle is composed of a heterogeneous group of intrusives. Accurate information regarding lithologic contacts within this complex is largely unavailable because an insufficient number of traverses were made to map such boundaries. In a few areas Jenks indicated contacts on his map. The rock types that are discussed below are mainly samples of limited areas the boundaries of which have not yet been mapped.

Included in this general intrusive stage are a wide range of rock types, from gabbro through diorite, tonalite, granodiorite, and quartz monzonite to granite. Jenks (1948, p. 169) considered these rocks to represent the fourth stage of igneous intrusion. Rethinking of the problem and reexamination of field notes shows that these varied rocks must have been largely in place by the time the Tiabaya granodiorite (Jenks' third stage) was intruded. There is no reason, however, to assert that all the Caldera intrusives are earlier than the Tiabaya.

In the 1948 paper it was observed that much of the Caldera intrusives to the southwest of the wedge or roof pendant of Mesozoic rocks, was quartz hornblende diorite of rather uniform texture and composition. Refinement by microscopic study shows a greater variety.

The gabbros, in general, occur as small masses. One such mass is a sill cutting the Jurassic Yura formation; the others are resistant inclusions in the Tiabaya granodiorite or are associated with other rocks of the Caldera complex south of the Arequipa-Vitor highway.

Modal analyses of two gabbros from the Caldera Range are given in Table 2, columns 1 and 2. The plagioclase is labradorite, about An60' with cores of zoned crystals as calcic as An84.

Only three of the specimens examined proved to be diorite. The modal composition of two are given in Table 2, columns 3 and 4. The plagioclase averages andesine (An50), but in one porphyritic specimen plagioclase in the groundmass is An40. Hornblende is in part an alteration of the pyroxenes.

Of 41 thin sections of Caldera intrusive rocks, 20, or nearly half, proved to be tonalite. Specimens from the Quebrada de Linga, and from the Chapi region likewise are tonalite. A few of the specimens examined are appreciably porphyritic, but uniformity of grain size is more normal.

The plagioclase ranges from An33 to An56; the average composition is An44, corresponding to andesine. Orthoclase and smaller amounts of microperthite make up 2 to 24 percent of the tonalites. Modal analyses of three representative specimens of these tonalites are given in Table 2, together with an average mode of 19 specimens which were fresh enough for effective study. The latter mode (in weight percent) is believed to be a reasonable approximation of the mineralogical composition of the most abundant rock in the whole Caldera Range.

TABLE 2

Modes (approximate weight percent) of rocks of the Caldera intrusives, Arequipa Quadrangle

	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz	--	--	4	4	34	23	13	18	20	32	24	21	29
K-feldspar	--	.2	4	16	13	19	16	16	30	24	24	42	41
Plagioclase	62	61.4	71	56	36	39	52	45½	34	35	34	29	23
Hornblende	--	36.8	8		--	6	15	11½	8	--	9	3	--
Biotite	--	--	12	17	12	11	2	5	4	7	5	3	5
Augite	19	--	--		--	--	--	--	--	--	--	--	--
Enstatite	8	--	--	5	--	--	--	--	--	--	--	--	--
Accessories	11	1.6	1	2	5	2	2	4	4	2	4	2	2
Total	100	100.0	100	100	100	100	100	100	100	100	100	100	100

1. Gabbro (AR376). 200 m. S of Arequipa-Ramal highway at km. 43. Accessories are magnetite (about 10.5%), apatite, and epidote.
2. Gabbro (AR367). Summit of Cerro Gloria, 6 km. SSE of Arenal station. Accessories are magnetite and sphene (1.4%) and epidote (0.2%).
3. Diorite (AR273). Pocsi-Quequeña trail, near pass 4 km. NE of Quequeña. Accessories are epidote, magnetite, and a trace of apatite.

4. Diorite (AR114). South slope of Cerro Chaquiaguada. Augite largely altered to hornblende, chlorite, and biotite. Accessories include epidote and calcite, which are alterations of femic minerals, and magnetite and apatite.

5. Tonalite (AR402). 3 km. W of Mina Torconta, north of Rio Vitor. Accessories are abundant epidote, some sphene and magnetite, and rare zircon.

6. Tonalite (AR374). SW ridge of Cerro San José, S of km. 44 of Arequipa-Ramal highway. Accessories are sphene, magnetite and apatite. Biotite with weak pleochroic halos.

7. Tonalite (AR370). South of Arequipa-Ramal highway at km. 49. Accessories are magnetite and minor apatite and epidote.

8. Average composition (weight percent) of tonalite (19 thin sections) from the Caldera intrusives.

9. Granodiorite (AR372). North of Arequipa-Ramal highway at km. 44. Accessories are magnetite, sphene, and apatite, with trace of zircon.

10. Granodiorite (AR303). Trail 4.5 km. S of Cerro Verde. Accessories and lateration products are hematite, epidote, and calcite.

11. Average composition (weight percent) of granodiorite (7 thin sections) from the Caldera intrusives.

12. Quartz monzonite (AR278). Rio Vitor at Morocoro, 5 km. NW of Vitor. Accessories are magnetite, epidote, apatite, and tourmaline.

13. Granite (AR357). Arequipa-Ramal highway at km. 42. Accessories are apatite, hematite, and a trace of zircon.

If the specimens studied are numerically representative of areas underlain by the various rocks, granodiorite is the second most abundant of the Caldera intrusives. Nine of the 41 specimens studied are granodiorite. Modal analyses of two of the granodiorites are given in Table 2 together with an average mode of seven specimens.

In the Caldera intrusives only five specimens were found to be quartz monzonites or granites, a reflection of the relative scarcity of these more acid rock types. Modal analyses of one specimen of each of these are given in Table 2. The plagioclase specimen of each is oligoclase (about An25).

TIABAYA GRANODIORITE

The Tiabaya granodiorite is the one major intrusive stage of the coastal batholith the contacts of which have been mapped completely on the reconnaissance scale of 1:200,000. This granodiorite is in two separate masses, one south of Tiabaya and the other south of Uchumayo (Jenks, 1948, plate 1). The former underlies an area of 55, the latter, 45 square kilometers.

The granodiorite and tonalite of the eastern body are light gray and have a hypautomorphic granular texture. The modal analyses given in Table 3 show the rather uniform character of this intrusive though some specimens prove to be granodiorite and others are potash-rich tonalite. The average modal ratio of plagioclase to potash feldspar, derived from the porcentages shown in colum 7 of Table 3, is .64. The same ratio in sample AR307, which was chemically analyzed, is .67. The composition of the plagioclase in the granodiorite as determined by extinction angles averages andesine, An40, while that of the tonalite is somewhat more calcic andesine. Potash feldspar is orthoclase, cryptoperthite and microperthite, all of which are present as anhedral grains. All feldspars have been sericitized to a moderate degree. Quartz, which makes up about 22% of these rocks, shows the irregular extinction indicative of strain.

TABLE 3

Modes (approximate weight percent) of granodiorite and tonalite of the Tiabaya granodiorite intrusives, Arequipa quadrangle.

	1	2	3	4	5	6	7	8	9
Quartz	21.1	21	19	23	17	29	21.7	10	19
K-feldspar	27.9	27	30	22	23	21	25.3	8	16
Plagioclase	41.4	41	43	40	42	45	42.0	50	51
Hornblende	5.2	9	5	--	14	--	5.5	22	8
Biotite	2.9	1	1	11	2	3	3.4	9	5
Accessories	1.5	1	2	4	2	2	2.1	1	1
Total	100.0	100	100	100	100	100	100	100	100
Modal ratio K-feldspar to plagioclase	.67	.66	.70	.55	.55	.47	.64	.16	.31

1. Granodiorite (AR307). Analyzed sample from railway cut at north end of eastern intrusive. Accesories are magnetite, spene, and apatite.
2. Granodiorite (AR224). Slope east of highway SW of Cerro Tiabaya, eastern intrusive. Accessories are magnetite, sphene, and minor zircon and epidote.
3. Granodiorite (AR165). Slope SW of Tiabaya railway station, eastern intrusive. Accessories are sphene, apatite, and magnetite.
4. Tonalite (AR40). South of railway at north edge of eastern intrusive. Accessories are magnetite, apatite, and minor epidote and zircon.
5. Tonalite (AR260). South slope of Cerro Lloron, at south end of eastern intrusive. Accessories are magnetite, epidote, and minor sphene and apatite.
6. Tonalite (AR142). Railway cut at north end of eastern intrusive. Accessories are magnetite, apatite, and traces of zircon, calcite, and muscovite.
7. Average of modes of six specimens from eastern body of Tiabaya granodiorite.
8. Tonalite (AR255). West slope of Cerro Gloria, western intrusive. Accesories are apatite, sphene, and magnetite.
9. Tonalite (AR314). East ridge of Cerro Gloria, SW of Quebrada del Ataque, western intrusive. Accesories are apatite, sphene, and magnetite.

The mafic minerals, hornblende and biotite together make up about 9% by weight of the eastern granodiorite intrusive. The hornblende is in subhedral to euhedral crystals with marked pleochroism, (x = pale yellow, y = brownish green, z = olive green). Some of the hornblende is twinned. Strongly pleochroic brown biotite is present in small amount; in some of the specimens it is the only ferromagnesian silicate present. Both hornblende and biotite show minor alteration to chlorite. Small dark pleochroic halos in some of the biotite are suggestive of the presence of monazite or xenotime (Hutton, 1947). Other accessory minerals, apatite, sphene, magnetite, and epidote are associated with the mafic minerals.

Because the uniformity of this rock was apparent in the field it was considered worth while to take a representative sample for chemical analysis. Special sample number AR307 was broken from blocks of freshly blasted granodiorite along the Southern Railway south of Tiabaya. Fresh chips were broken from clean blocks over an area of about 100 square meters. The analysis was done at the University of Minnesota and is given in Table 4, together with the calculated norm.

TABLE 4

Chemical analysis and norm of sample AR307 from railway cut at the north edge of the eastern body of Tiabaya granodiorite

Analysis *		Norm	
SiO_2	67.30	Q	24.05
Al_2O_3	15.44	or	21.72
Fe_2O_3	1.77	ab	26.20
FeO	1.83	an	17.32
MgO	1.52	di	2.75
CaO	4.19	hy	3.92
Na_2O	3.10	mg	2.55
KaO	3.68	il	0.61
H_2O+	.35	ap	0.31
H_2O—	.07		
TiO_2	.32		99.43
P_2O_5	.15		
MnO	.10		
Total	99.82		
Total	99.32		

An in plagioclase:
Norm. 40%
Mode: 40% (cores) to 26% (borders)

* Analyst: Eileen H. Osland, Laboratory for Rock Analysis, University of Minnesota.

Ratio K-feldspar to Na-Ca- feldspar:
Norm: .50
Mode: .67

It has been noted that the modes of five other specimens from the eastern body of Tiabaya granodiorite do not vary greatly from that of AR307. Even those rocks classified as tonalites are not greatly different from the granodiorites. It therefore appears that the chemical analysis of sample AR307 is nearly representative of the average composition of the eastern granodiorite body, with an area of 55 square kilometers. To the best of the authors' knowledge this is the first essentially complete analysis of a coastal batholith intrusive in Peru.

More field work should precede additional chemical study of the batholith, in order to be certain of the extent and relationships of each of the rocks analyzed.

The western stock correlated with the Tiabaya granodiorite is more basic, as is shown by the two tonalite modes given in Table 3, columns 8 and 9. The correlation is believed to be valid on the basis of similarities in structure and contact relations.

LATE ACID INTRUSIVES

The late acid intrusives of the Caldera Range are small granite stocks, relatively unimportant as far as volume of intruded material, but significant because they may have been related to the same late magma from which the quartz- tourmaline-copper mineralization of the region was derived. The most striking features of these granites is the abundance of a micrographic intergrowth of quartz and orthoclase. Some of the quartz is apparently late and related in age to minor amounts of tourmaline through the rock.

AVERAGE COMPOSITION

The part of the batholith within the Arequipa quadrangle is a fair sample of what may be expected in the coastal batholith elsewhere in the southern Departaments of Arequipa and Moquegua. It is not possible, of course, to extend the results of present study to more distant parts of the batholith.

To give an approximation of the average composition and magmatic history of the batholith in the area studied, specimens have been listed in Table 5 according to relative age and rock classification. Of 75 specimens studied in thin section, only 59 have been included in the table. The others have been eliminated because of near duplications in sampling or because they show excessive weathering. Percentages showing frequency of occurrence of rock type regardless of relative age are given in the next to the last column. Among these specimens the dominance of tonalite and granodiorite is apparent. In this listing, however, the relative abundance of gabbro and granite is excessive because the number of specimens taken of them is large in proportion to the areas underlain by each of these rocks. A qualitative estimate of the approximate areal abundance of the six rock types is therefore given in the last column of Table 5. These estimates are based on the senior author's knowledge of the area combined with careful study of the distribution of rock types determined in thin section.

TABLE 5

Distribution of rock types by apparent order of intrusion

	1	2	3	4	5	Total	Percent of samples	Estimated percent of area
Gabbro			3			3	5.1	1
Diorite		2	3			5	8.5	8
Tonalite	2	1	22	5		30	50.9	55
Granodiorite	1	1	6	3		11	18.6	25
Quartz monzonite	1		3			4	6.8	7
Granite			2		4	6	10.1	4
Total	4	4	39	8	4	59	100.0	100

1. Huasamayo tonalite
2. Tingo complex
3. Caldera intrusives
4. Tiabaya granodiorite
5. Late acid intrusives

The average composition of the batholith within the quadrangle would fall within the range of tonalit , on the alkalic side close to granodiorite. Expecially notable is the small amount of gabbro. There is no indication that gabbro is anywhere the earliest rock; on the contrary, field evidence suggests that the small gabbro masses are most closely related to the highly varied Caldera intrusives. On the other hand, the preponderance of granites in the latest intrusives is clear.

COMPARISON WITH THE BATHOLITH OF SOUTHERN CALIFORNIA

The batholith in the Arequipa quadrangle is similar in many ways to that of southern California, described by Larsen (1948). The California intrusives are Cretaceous, while those near Arequipa are late Cretaceous or early Tertiary (Jenks, 1948). The two regions are in similar tectonic settings with relation to the circumpacific border. Disregarding detailed geologic histories, each batholith is in a geosynclinal zone where Mesozoic sediments and volcanics accumulated in abundance and were folded prior to major plutonic activity.

In each area the most abundant rock and the probable average composition is tonalite. Also in each area granodiorite is the second most abundant rock. Gabbros occupy a smaller proportion of the batholithic area near Arequipa than they do in southern California.

Both batholiths are complex. The early Huasamayo tonalite of the Arequipa area is characterized throughout by gneissoid and cataclastic textures developed early in the history of the batholith. According to Larsen (1948, p. 140) such features are lacking in the southern California intrusives except near contacts.

Late tourmaline and quartz are present in abundance in parts of the Arequipa quadrangle, where they are related to copper mineralization (Jenks, 1948, pp. 187-188). Tourmaline is also an accessory mineral in plutonics outside the main tourmaline zone. In southern California similar introduced tourmaline and quartz intergrowths are present in many places

(Larsen, 1948, p. 106), but are not associated with copper. Epidote is rather widely disseminated through the Arequipa rocks and is partly deuteric and partly, along with some quartz, hydrothermal. In general the southern California rocks appear to contain much less epidote.

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REFERENCES

DOUGLAS, J. A. 1920. Geological Sections through the Andes of Peru and Bolivia: Part II, from the Port of Mollendo to the Inambari River; Quart. Juor. Geol. Soc. London, vol. LXXVI, pp. 1-50.

HUTTON, C. O. 1947. The Nuclei of Pleochroic Haloes; Am. Jour. Sci., vol. 245, pp. 154-157.

JENKS, W. F. 1948. Geology of the Arequipa Quadrangle; Inst. Geol. del Perú, Bol. 9, Lima, 204 pp.

LARSEN, E. S., Jr. 1948. Batholith and Associated Rocks of Corona, Elsinore, and San Luis Rey Quadrangles, southern California: Geol. Soc. Amer., Memoir 29, 182 pp.

STOSE, G. W., ed. 1950. Geologic Map of South America. Publ. by Geol. Soc. Amer., New York.

WAHLSTROM, E. E., 1947, Igneous Minerals and Rocks: John Wiley and Sons, Inc., New York, 367 pp.