Earth-Science Reviews, 18 (1982) 253–283
Elsevier Scientific Publishing Company, Amsterdam—Printed in The Netherlands

Present Knowledge of the Magmatic Evolution of the Eastern Cordillera of Peru

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ABSTRACT

Carlier, G., Grandin, G., Laubacher, G., Marocco, R. and Mégard, F., 1982. Present knowledge of the magmatic evolution of the Eastern Cordillera of Peru. Earth-Sci. Rev., 18: 253–283.

The studies which have been carried out in the Eastern Cordillera of Peru over the past 20 years prove the existence of at least three orogenic cycles: the Late Precambrian, the Hercynian and the Andean, each one accompanied by a more or less abundant magmatism.

(1) The *Precambrian*. Leaving aside the prasinites, possibly derived from synsedimentary volcanites, Precambrian magmatism (in the Huanuco region) consists of: a meta-igneous ultramafic to mafic association (serpentinites, meta-gabbros, meta-diorites); syntectonic meta-tonalites; and post-tectonic dioritic and granitic intrusive bodies.

(2) The *Hercynian (550 to 220 m.y.)*. From the Cambrian to the Upper Devonian the existence of a synsedimentary magmatism is known. Syntectonic granites were emplaced during the Eohercynian phase, but the major part of magmatism is of a Late Permian to Early Trias age, and is characterized by the intrusion of granitoids and by volcanism of calc-alkaline tendency. It appears that the nepheline syenite of Macusani may belong to a terminal episode of this magmatic period.

(3) During the *Andean evolution* there is considerably less magmatism in the Eastern Cordillera than during the preceding cycles. Plutonism, which is essentially acid, is only well represented in central Peru. Volcanic rocks are more abundant and more widely distributed.

Knowledge of the Precambrian is still insufficient to enable us to place the magmatism of this orogenic belt in a geodynamic context. It seems that the Hercynian magmatism is related to extension episodes affecting a continental crust. On the other hand, it is probable that the Andean magmatism of the Eastern Cordillera is linked, at least indirectly, to the presence of an active convergent margin to the west of Peru, dating from the Mesozoic.

0012-8252/82/0000–0000/$07.75

INTRODUCTION

The Cordillera of the Peruvian Andes is made up of morphostructural units which followed their own particular evolution during the geological history of the Pacific margin of the central Andes (Peru-Bolivia-northern Chile and northern Argentina). From west to east the following units are

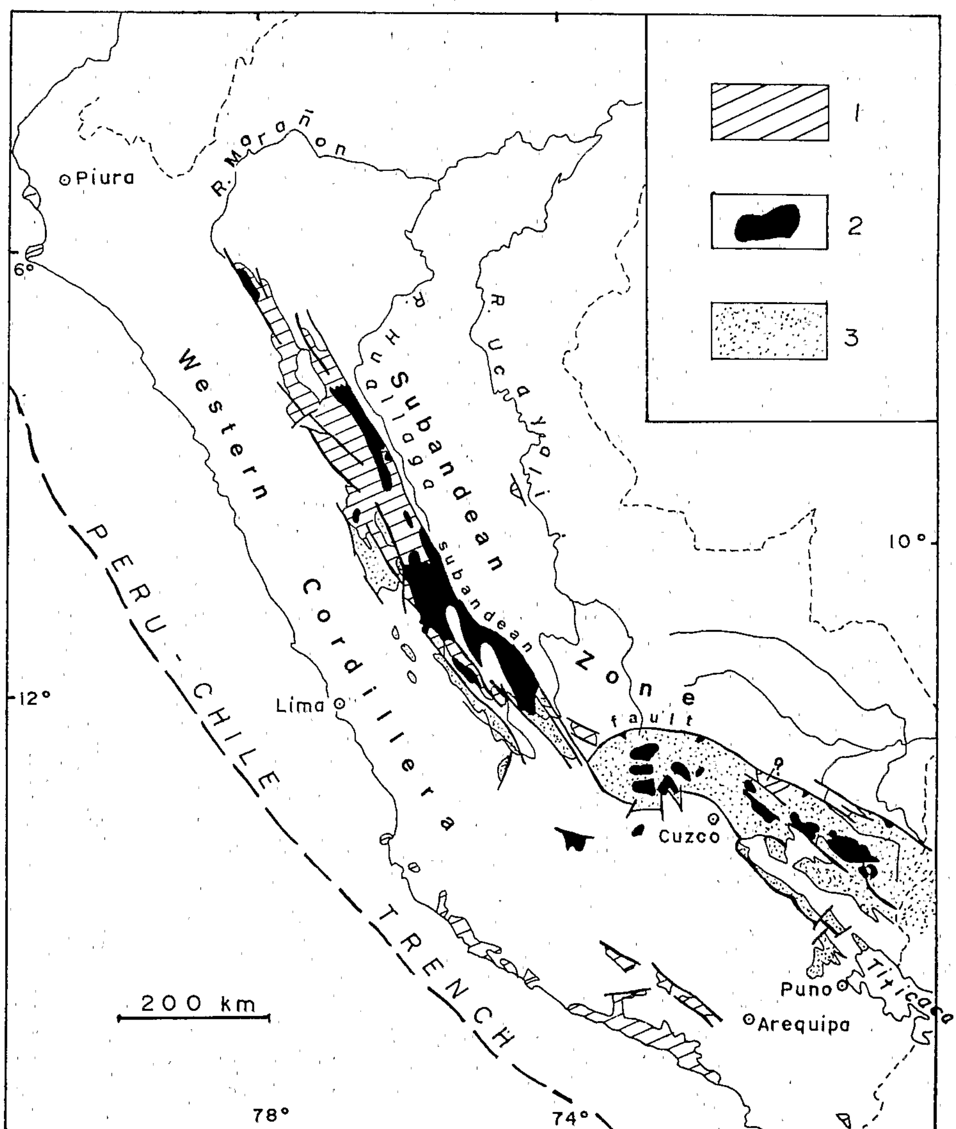

Fig. 1. Geologic sketch of the Eastern Cordillera of Peru. *1* = Precambrian outcrops; *2* = Hercynian plutons; *3* = Hercynian orogenic belt.

found: the Coastal Zone, the Western Cordillera, the high Andean plateaus and/or the Altiplano, the Eastern Cordillera, the sub-Andean zone and the Brazilian Shield.

Among these units, the Eastern Cordillera (Fig. 1) is of special interest, for in it there are recorded the three main orogenic cycles which constitute the Central Andes chain, namely the Precambrian, Hercynian and Andean. South of 11°S (approximately), the Eastern Cordillera forms the axial zone of the Hercynian belt (Mégard et al., 1971; Dalmayrac et al., 1977). North of this parallel, the Hercynian axial zone probably lies farther west, so that the Eastern Cordillera is composed mainly of Precambrian rocks, locally covered by Paleozoic rocks, which were deformed very little during the Hercynian phase, and also by some Andean rocks. The Andean cycle, of Mesocenozoic age, has superimposed NNW–SSE structures onto pre-existing Precambrian and Hercynian structures.

The distribution of the principal magmatic units is dictated by the composite nature of the Eastern Cordillera. North of 11°S, the magmatism is Precambrian; to the south it is mainly Hercynian (ante-syn-post-tectonic). Only the Eastern Cordillera of Central Peru shows a widespread Andean magmatism (see Fig. 7).

PRECAMBRIAN MAGMATISM

The Precambrian formations of the Eastern Cordillera constitute two large outcrops in Central Peru (between 6° and 13°S) (Fig. 2): (1) to the north, the Marañon Massif between Pataz and Huanuco; (2) to the south, the Huayta-pallana and Jabo-nillo massifs. The Quincemil orthogneiss (75 km to the NE of Cuzco) is possibly the southernmost Precambrian outcrop (Mégard et al., 1971).

The Precambrian is represented mainly by a polymetamorphic and poly-deformed detrital series. The metamorphism is characterized by two phases (Dalmayrac 1978; Mégard, 1978). An M_1 phase of intermediate pressure (Barrovian) reaches the granulite facies (catazone) towards the east. This phase is recognizable only in relict phenoblasts cast in the S_2 cleavage. Granulites of this episode have been dated at 600 ± 50 m.y. using the U-Pb method on zircons (Dalmayrac, 1978). The M_2 phase is of low-pressure type (Abukuma) and is only represented by epizonal and mesozonal facies.

Four phases of deformation have been recognized in the Precambrian rocks: (1) an isoclinal phase P_1, synchronous with the M_1 metamorphism; (2) a P_2 phase, also isoclinal, synchronous with the M_2 metamorphism, that gives rise to the schistosity S_2 visible on the outcrops; (3) a post-metamorphic P_3 phase leading to a cleavage S_3; (4) a P_4 phase, characterized by concentric folds and kink-bands.

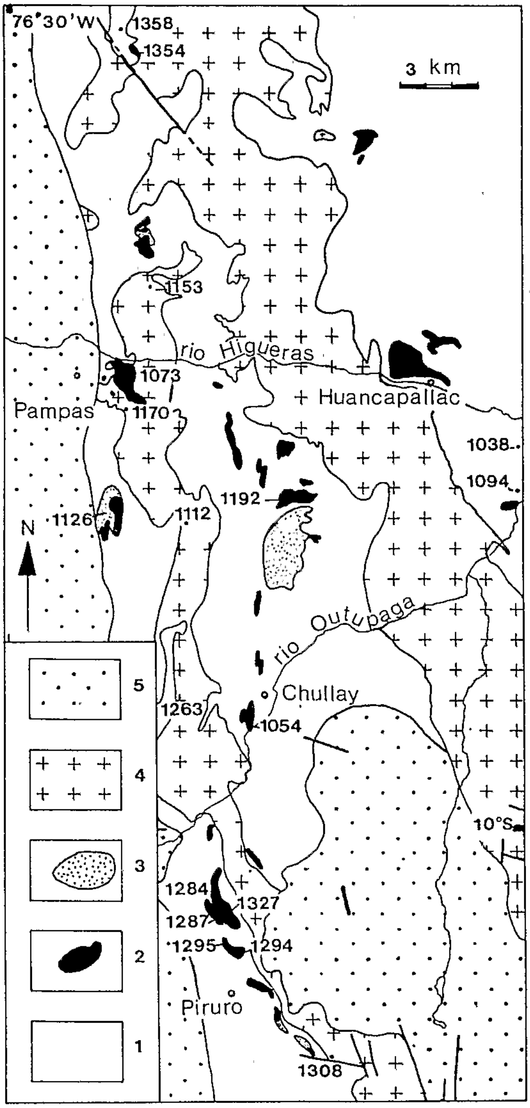

Fig. 2. Simplified geological map of the Huancapallac region Precambrian rocks (Marañon Massif, northern Peru). *1* = micaschists; *2* = serpentinites; *3* = metagabbros; *4* = undifferentiated granitoids and orthogneisses; *5* = Upper Paleozoic sedimentary rocks.

The magmatism of the Precambrian belt has as yet been little studied. However, the studies of Dalmayrac (1978), Mégard (1978), Harrison (1951), Steinmann (1929), Aumaître et al. (1977) added to those carried out by two of the present authors (G.C. and G.G.), west of Huanuco (Fig. 2), allow us to define the following magmatic groups: (1) acid and basic synsedimentary rocks; (2) ultrabasic and basic complexes; (3) orthogneiss bodies; (4) post-tectonic intrusions.

Acid and basic synsedimentary rocks

The oldest magmatic events found are characterized by basic and acid intercalations in the sand–shale series. There are good examples of these intercalations in the Marañon Massif at Balsas and Huanuco (Aumaître et al., 1977) as well as in the Huaytapallana Massif at Comas, Tapo and San Rafael (Harrison, 1951; Paredes, 1972; Mégard, 1978). Evidence of all the deformation and metamorphism phases is found in them. These are typical albite-chlorite-actinote-tremolite-quartz prasinites and oligoclase-hornblende orthoamphibolites (Harrison, 1951). The acid material is represented by meta-rhyolites situated in the upper part of the Precambrian series (Aumaître et al., 1977). These rocks are considered to be related to acid and basic synsedimentary volcanic episodes. Since the M_1 metamorphism which affects them is dated at ~ 600 m.y. (Dalmayrac, 1978), a Late Precambrian age can be attributed to them.

Ultrabasic and basic complexes

Ultrabasic and basic complexes constitute small decametric to kilometric massifs forming north–south alignments (Aumaître et al., 1977). These are more frequent in the Marañon Massif (Huancapallac, Chinchao) than in the Huaytapallana Massif (Tapo). They would seem to be thrust slices which came to rest during the P_2 phase. They are affected by the M_2 metamorphism and the P_2 phase. The complexes consist mostly of serpentinites, in which relicts of dunites, harzburgites and pyroxenites have been recognized. The associated basic rocks are gabbros, norites and anorthosites (Aumaître et al., 1977). Related to them are found sills and dykes of amphibolites, characterized by the abundance of apatite and titanic-iron oxides. The basic rocks seem to belong to a tholeiitic series (Table I, Figs. 6, 7). The ultrabasic and basic complexes are younger than the M_1 metamorphism, and in the Huanuco region they are covered unconformably by Lower Paleozoic shales. A Late Precambrian to Cambrian age can be attributed to them.

Orthogneiss bodies

These have only been recognized in the Marañon Massif (Huancapallac, Balsas) and seem to be located in the least metamorphic parts of the Precambrian belt. They consist of granites, granodiorites and tonalites which have been deformed by cataclasis during the P_3 phase. They are porphyroblastic rocks of a quartz-oligoclase-orthose/microcline-biotite-muscovite composition. Andesine and green hornblende appear in some of the more basic of these orthogneisses. Lack of chemical analyses prevents us from defining the nature of these intrusions. As the P_3 phase (S_3 schistosity) does not affect the Lower Paleozoic, a Late Precambrian to Cambrian age can be ascribed to these rocks.

Post-tectonic intrusions

In the Huancapallac region of the Marañon Massif, the Precambrian series have been affected by a contact-metamorphism provoked by the intrusion of diorites, granodiorites and granites. Diorites were first intruded and were followed by granodiorites and granites. The diorites have a prophyric texture: they are rocks of a green hornblende-andesine/labradorite-biotite composition; clinopyroxene sometimes appears as relicts. The granites and granodiorites made up of a biotite, orthose/microcline, albite/oligoclase and accessory muscovite have a xenomorphic granular texture. This magmatic episode shows a calc-alkaline tendency (Table I, Figs. 6, 7). The absence of a clear relation between these post-tectonic intrusions and the Lower Paleozoic renders it impossible to either confirm or discard a pre-Llanvirnian age. At least, part of them are pre-Carboniferous, since they are covered unconformably by the Ambo Group to the south of Chullay.

HERCYNIAN MAGMATISM

The largest outcrops of Hercynian magmatic products are to be found in the Eastern Cordillera. The Hercynian orogenic cycle is marked in the Upper Devonian–Lower Carboniferous by an important tectonic event: the Eohercynian phase (Mégard, 1967). The Hercynian magmatism will be described as ante-, syn- and post-tectonic in relation to the Eohercynian orogeny. The second Hercynian tectonic phase, of Middle Permian age (the Tardi-Hercynian phase of Audebaud and Laubacher, 1969), will not be taken into consideration for the nomenclature of orogenic magmatism.

Ante-tectonic magmatism

We shall distinguish two ante-tectonic units: *initial magmatism*, prior, or sub-contemporary, to the formation of the sedimentary basin of the Lower Paleozoic, and *synsedimentary magmatism*, intercalated in the marine rocks.

Initial magmatism. In the Eastern Cordillera of the Cuzco region, nearly 1000 m of sandstones, shales, green pyroclastics and welded tuffs lie conformably below the Lower Ordovician (Arenig). This is the Ollantaytambo series (Marocco and Garcia Zabaleta, 1974).

This pre-Early Ordovician volcanic episode is also found in the Marcapata Valley and in the sub-Andean zone of central Peru (Shira) where, in the Lower Ordovician dated by Didymograptus, arkoses, conglomerates and basalts are found (Mégard, 1978). Volcano-sedimentary green rocks possessing the same stratigraphic connections, are also known in the Bolivian Chapare (Frankl, 1958), and in northwestern Argentina (Turner, 1970). Note that in the Western Cordillera of central Peru, the green volcanosedimentary rocks (pyroclastics and lavas, perhaps andesitic in nature) attributed to the indifferentiated Lower Paleozoic by Mégard (1978), could possibly correspond to this initial magmatic episode.

The Lower Paleozoic sedimentation was therefore preceded by volcanic activity related to the fracturing which gave rise to the subsident Lower Paleozoic sedimentary basin.

Synsedimentary magmatism. Magmatic events are relatively few in number in the Lower Paleozoic record; in particular, the total absence of ultrabasic rocks must be noted. A few intercalations of volcanclastic and acid volcanic rocks have been pointed out in central Peru (Mégard, 1978). Basaltic sills and some pyroclastics have been recognized in the Eastern Cordillera and the Altiplano of southern Peru (Laubacher, 1978). However, the major part of synsedimentary magmatism is localized on the Amazonian side of the Andes, principally along the limit between the Cordillera and the sub-Andean zone. It is composed of either andesitic dykes and sills (Quillabamba) (Marocco, 1978), or of olivine basalts (Alto Madre de Dios-Rio Inambari) (Laubacher, 1978). In the Tambo-Perene zone (11°S), Martin and Paredes (1977) point out a 30 m thick flow of olivine-augite basalt that yielded a K/Ar minimal age of 331 ± 20 m.y. This basic magmatism might be linked to a fracturing of the eastern border of the Hercynian sinking basin during the Lower Paleozoic and, more especially, the Devonian.

Syntectonic magmatism

One of the particularities of the Hercynian belt of the Central Andes is that it shows an acid magmatism contemporary with the Eohercynian tectonism. Two massifs of this kind have already been described: Zongo-Yani in Bolivia (Bard et al., 1974) and Amparaes in Peru (Marocco, 1978). The granites of San Gaban (Laubacher, 1978) and of Marcapata, both located in southern Peru (Fig. 3) may also be ascribed to this syntectonic magmatism.

The Amparaes Massif (13°S 72°10'W). This is a granite orthogneiss (sample 450, Table I) of a quartz-microcline-plagioclase (An20)-biotite-epidote-muscovite composition; it is covered by 500 m of orthoamphibolites,

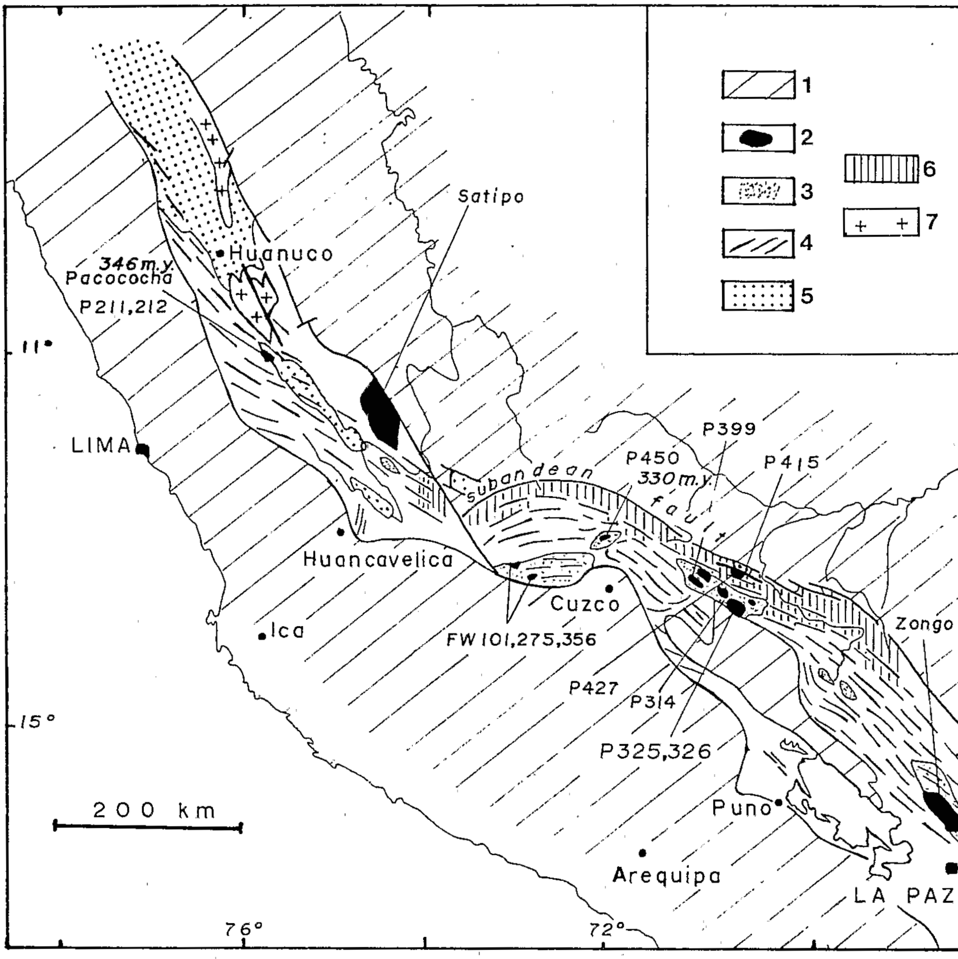

Fig. 3. Magmatism related to Eohercynian orogeny. *1* =post-Permian rocks; *2* =Eohercynian plutons; *3*; Eohercynian metamorphism; *4* =Eohercynian cleavage; *5* =Precambrian outcrops; *6* =syn-sedimentary Siluro–Devonian magmatism; *7* =composite batholiths including possible Eohercynian intrusions. P211, P212: Pacococha batholith; P450: Amparaes Eohercynian syntectonic granite; P427: Marcapata Eohercynian orthogneiss; P415: Marcapata Precambrian (?) orthogneiss; P325, P326: San Gaban batholith.

cut into a canyon by the Rio Yanatile. Above them lie staurolite and cordierite-bearing micaschists, calc-magnesian marbles and para-amphibolites. A N50°E-trending antiform affects the whole of the metamorphic series as well as their foliation.

The petrographical and structural study of the samples from the Amparaes Massif (J.P. Bard in Marocco, 1978) and the field survey show that this orthogneiss is a syntectonic granite, which caused a low-pressure syntectonic contact metamorphism in the countryrocks. The study of the

TABLE I

Major analysis of Eastern Cordillera rocks. All iron calculated in Fe_2O_3 except in samples FW. Samples 1130 to 1308 were analysed by X-ray quantometry in University of Grenoble (France). Samples P415 to JP71b were analysed in CRPG of Nancy (France). Samples FW after Fricker and Weibel (1960). See localization in Figs. 2, 3 and 4.

	1170	1358	1153	1112	1294	1263	1094	1038	1327	1126	1192	1287
SiO_2	50.42	49.26	52.09	49.39	58.04	50.76	49.17	48.16	50.44	51.59	41.31	41.18
TiO_2	0.85	2.12	1.58	1.09	1.16	2.10	2.13	1.99	0.34	0.43	0.06	0.05
Al_2O_3	15.64	16.26	18.14	15.96	16.04	16.18	15.72	15.36	16.01	15.97	1.98	1.69
Fe_2O_3 *	10.23	11.72	9.21	9.94	7.17	11.17	12.48	13.29	6.19	5.96	10.10	9.01
FeO	–	–	–	–	–	–	–	–	–	–	–	–
MnO	0.23	0.38	0.15	0.18	0.17	0.21	0.21	0.25	0.15	0.18	0.19	0.11
MgO	7.82	5.12	4.10	7.41	3.66	4.39	3.91	5.42	9.26	9.18	39.67	35.56
CaO	10.96	6.91	7.69	9.67	4.79	7.78	8.84	8.16	12.04	10.35	0.29	0.14
Na_2O	n1.57	3.61	3.61	1.99	3.43	3.54	3.00	3.60	3.35	3.05	0.01	–
K_2O	0.30	0.63	1.24	1.52	2.37	0.90	1.09	0.26	0.19	0.23	0.01	0.01
P_2O_5	0.13	0.32	0.28	0.18	0.20	0.33	0.45	0.34	0.11	0.13	–	–
H_2O^+ H_2O^-	1.20	2.14	2.16	2.23	2.06	1.11	0.72	2.78	1.63	2.17	4.84	11.67
TOTAL:	99.35	98.47	100.25	99.56	99.09	98.47	97.12	99.61	99.71	99.24	98.46	99.42
quartz	–	–	0.53	–	10.02	–	–	–	–	–		
orthose	2.34	3.89	7.23	8.90	13.90	5.00	6.67	1.67	1.11	1.11		
albite	13.10	30.39	30.39	16.77	28.82	29.87	25.15	30.39	27.25	26.20		
anorthite	34.75	26.13	29.75	30.02	21.41	26.97	26.13	25.30	28.08	29.19		
nepheline	–	–	–	–	–	–	–	–	0.57	–		
diopside	15.34	4.97	5.18	13.39	1.30	8.64	11.93	10.58	26.09	18.65		
hypersthene	27.81	19.48	20.04	18.86	17.58	20.13	18.48	9.73	–	15.30		
olivine	–	5.43	–	5.78	–	1.44	2.26	13.85	13.16	4.34		
magnetite	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09		
apatite	0.33	0.67	0.67	0.33	0.33	3.95	1.01	0.67	0.33	0.33		
ilmenite	1.67	4.10	3.04	2.13	2.28	0.67	4.10	3.80	0.61	0.76		
corindon	–	–	–	–	–	–	–	–	–	–		

TABLE I (continued)

	1054	1073	1354	1289	1295	1308	P 415	P 427	P 314	P 325	P 326	P 399
SiO_2	36.50	39.18	41.94	42.43	42.40	41.30	67.58	75.85	69.83	65.53	62.06	73.59
TiO_2	0.11	0.07	0.07	0.05	0.05	0.07	0.51	0.24	0.48	0.80	1.02	0.23
Al_2O_3	1.37	2.20	2.22	1.61	1.90	1.81	15.87	10.83	14.64	16.03	18.41	14.47
Fe_2O_3 *	9.56	9.13	6.88	9.02	9.90	8.98	3.06	4.34	3.41	4.07	5.68	1.71
FeO	–	–	–	–	–	–	–	–	–	–	–	–
MnO	0.20	0.10	0.06	0.09	0.14	0.10	0.06	–	0.06	0.06	0.07	0.05
MgO	37.85	38.21	36.44	34.45	39.42	35.00	0.84	–	0.84	1.26	1.55	0.56
CaO	0.17	0.69	0.28	0.04	0.10	0.21	2.58	0.35	1.80	1.68	2.28	1.83
Na_2O	–	0.15	–	0.04	0.12	–	4.58	3.53	3.22	3.45	2.77	3.60
K_2O	0.01	0.04	0.27	0.02	0.02	0.02	3.00	3.24	4.21	4.92	4.31	3.43
P_2O_5	0.01	0.01	0.01	0.02	0.01	0.01	–	–	–	–	0.60	–
H_2O^+ H_2O^-	12.46	8.90	9.31	8.99	5.35	11.80	0.72	0.18	0.98	1.17	0.24 0.92	0.54
TOTAL:	98.24	98.68	97.48	96.76	99.41	99.30	98.80	98.56	99.47	98.97	99.91	100.01
quartz							22.87	41.18	29.81	20.84	20.84	34.95
orthose							18.11	19.46	25.31	29.81	26.06	20.38
albite							39.58	30.36	27.72	29.93	23.98	30.63
anorthite							13.07	1.77	9.09	8.55	11.57	9.13
diopside							–	–	–	–	–	–
hypersthene							2.75	3.65	3.39	5.05	8.16	1.40
magnetite							2.23	2.22	2.22	2.24	2.23	0.11
hematite							–	–	–	–	–	1.44
ilmenite							0.99	0.46	0.93	1.56	1.99	0.44
corindon							0.40	0.89	1.54	2.02	5.16	1.52
											0.33	

	FW 101	FW 275	FW 356	P 450	P 211	P 212	P 381	P 386	P 387	P 393	FW 151	FW 353
SiO_2	52.90	50.80	50.40	73.47	75.03	74.63	71.79	73.98	69.70	70.41	73.00	66.90
TiO_2	2.00	1.70	2.20	0.23	–	0.01	0.31	0.23	0.50	0.57	0.08	0.56
Al_2O_3	14.20	16.50	14.50	13.98	13.41	12.67	14.28	13.45	14.80	14.95	13.80	15.20
Fe_2O_3 *	3.20	2.60	5.40	2.08	1.23	1.59	2.35	2.15	3.48	3.00	0.72	1.25
FeO	6.80	8.10	6.10	–	–	–	–	–	–	–	0.07	1.61
MnO	0.09	0.11	0.10	0.10	0.05	0.04	–	–	0.04	0.07	–	0.03
MgO	5.50	4.70	6.00	0.67	0.09	0.54	0.48	0.10	0.73	0.98	0.20	1.30
CaO	7.40	6.40	8.00	2.29	0.56	0.43	1.56	0.94	1.44	2.15	0.80	1.65
Na_2O	3.30	3.00	3.60	4.07	3.94	3.91	3.51	3.67	2.90	3.47	4.10	5.40
K_2O	1.55	1.90	1.65	2.88	4.17	3.54	4.26	4.64	5.09	3.82	5.50	4.50
P_2O_5	–	–	–	0.10	–	–	0.10	–	–	–	–	–
H_2O^+	2.20	3.50	1.50	0.02	0.63	1.09	0.02	0.26	0.94	0.59	1.40	0.90
H_2O^-				0.45			0.53	–				
TOTAL:	99.14	99.31	99.45	100.34	99.11	98.45	99.19	99.42	99.62	100.01	99.67	99.30
quartz	4.54	2.08	0.12	33.17	35.34	37.60	31.41	–	29.02	29.55	26.75	13.44
orthose	9.45	11.72	9.95	17.09	25.03	21.49	25.57	27.24	30.55	22.74	33.08	27.03
albite	28.81	26.49	31.10	34.33	33.86	33.99	30.17	30.92	24.92	29.58	35.31	46.44
anorthite	19.97	27.07	18.92	11.41	2.82	2.19	7.86	4.73	7.26	10.58	3.05	4.00
diopside	14.47	4.99	17.14	–	–	–	–	–	–	–	0.76	3.45
hypersthene	14.03	20.32	10.47	1.67	0.23	1.38	1.21	0.30	3.14	2.89	0.15	2.71
wollastonite	–	–	–	–	–	–	–	–	–	–	–	–
olivine	–	–	–	–	–	–	–	–	–	–	–	–
magnetite	4.80	3.95	8.02	1.02	0.17	0.37	1.61	0.23	2.22	2.20	–	1.85
hematite	–	–	–	0.81	1.14	1.29	0.41	1.28	–	–	0.74	–
ilmenite	3.93	3.38	4.28	0.44	–	0.02	0.60	0.46	0.97	1.09	0.15	1.08
corindon	–	–	–	0.05	1.42	1.67	1.07	0.71	1.93	1.21	–	–

TABLE I (continued)

	FW 184	FW 214	P 434	P 446	P 456	P 459	P 537	JP 71b	TA319b	JP 67	JP 64	TA 316
SiO_2	69.60	55.70	69.33	68.42	59.40	62.45	74.13	71.68	70.31	69.56	69.91	65.80
TiO_2	0.40	1.54	0.51	0.41	0.66	0.63	0.18	0.32	0.38	0.34	0.32	0.74
Al_2O_3	14.40	16.80	14.78	15.81	18.11	17.21	13.68	13.66	14.71	14.73	15.00	14.37
Fe_2O_3 *	0.63	2.30	3.61	3.15	5.31	4.97	1.84	2.61	2.91	2.94	2.74	5.56
FeO	2.10	6.00	–	–	–	–	–	–	–	–	–	–
MnO	0.03	0.09	0.05	0.05	0.08	0.08	0.05	0.07	0.07	0.07	0.06	0.11
MgO	0.80	2.50	0.71	0.88	2.78	2.16	0.32	0.53	0.64	0.66	0.57	1.31
CaO	0.95	4.00	1.49	2.39	5.17	5.21	1.29	1.00	1.44	1.09	1.39	1.98
Na_2O	4.40	4.40	3.51	3.83	3.84	4.03	3.80	3.62	4.08	4.12	3.71	3.92
K_2O	4.90	4.00	5.00	3.08	1.49	1.99	3.99	4.52	4.60	5.06	5.15	4.52
P_2O_5	–	–	–	0.14	–	–	0.10	0.10	0.11	0.10	0.10	0.20
H_2O^+				0.06			0.05	0.07	0.07	0.10	0.04	0.03
H_2O^-	1.50	1.60	0.86	1.15	1.81	0.90	0.32	1.22	0.64	0.62	0.27	0.61
TOTAL:	99.71	98.93	99.85	99.37	98.65	99.63	99.75	99.40	99.96	99.39	99.26	99.15
quartz	21.15	0.64	25.14	28.15	14.78	16.24	33.79	30.94	24.90	22.93	24.91	18.19
orthose	29.49	24.28	29.91	18.61	9.13	11.95	23.78	27.29	27.46	30.38	30.83	27.28
albite	37.91	38.25	30.07	33.14	33.69	34.66	32.43	31.29	34.88	35.42	31.80	33.88
anorthite	4.80	14.66	7.48	12.12	26.59	23.37	6.46	5.07	7.22	5.49	6.99	8.44
diopside	–	4.75	–	–	–	2.37	–	–	–	–	–	1.34
hypersthene	4.81	10.97	3.31	3.08	11.44	7.96	0.80	1.55	2.21	2.40	1.84	7.21
magnetite	0.93	3.44	2.21	2.23	2.26	2.22	0.32	2.23	2.20	2.22	2.21	2.23
hematite	–	–	–	–	–	–	1.30	–	–	–	–	–
ilmenite	0.78	3.01	0.98	0.80	1.30	1.22	0.35	0.62	0.73	0.66	0.62	1.44
corindon	0.13	–	0.89	1.87	0.81	–	0.77	1.01	0.40	0.50	0.80	–

crystallization–deformation relationships in the micaschists permit a reconstitution of the evolution of the intrusion. The emplacement of the granite occurred towards the end of a first stage of deformation, bringing about a biotite-staurolite-cordierite aureole in the country-rocks. A second period of deformation gneissified the granite. These two tectonic periods correspond to two pulses of the first Eohercynian phase (EW to N120°E). The second Eohercynian phase seems to be responsible for the formation of the antiform with a N50°E-axis.

The emplacement of the Amparaes othogneiss has been dated at 330 ± 10 m.y. (U–Pb on zircons) by J.R. Lancelot (Lab. Géochim. Isotop., Univ. Montpellier, France). Similar Rb–Sr ages have been obtained on the Zongo-Yani Massif (U. Cordani, oral commun.).

The other syntectonic massifs. These are chiefly the San Gaban and Marcapata massifs. Their position in the chain is the same as that of Amparaes and Zongo-Yani massifs; their mineral and chemical compositions are identical.

Within the country-rocks of Late Paleozoic age folded by the Eohercynian phase, these two massifs gave rise to a thermal metamorphism, characterized by andalusite, cordierite, staurolite, biotite, sillimanite, garnet and muscovite. The metamorphism is localized around the orthogneissic granites. The study made by Laubacher (1978), although incomplete, shows clearly the syntectonic character of the San Gaban Massif, of which the U–Pb radiometric dating is being undertaken at the moment.

In the Eastern Cordillera of central Peru, along the Toctuga–Satipo cross-section, Mégard (1978) describes deformed granites which are older than the Early Permian, and could well be contemporary with the Eohercynian tectonic phase.

We also attribute provisionally to the Eohercynian syntectonic magmatism the deformed intrusive rocks intruded by Permian granites of the Vilcabamba Cordillera, described by Fricker and Weibel (1960) that bear numbers 101,275 and 356 (Table I).

Post-tectonic magmatism

The major part of the volcanism and plutonism posterior to the Eohercynian tectonic phase settled during the Upper Permian and Lower Trias. However, magmatic products (essentially volcanic) are never completely absent from Permo-Carboniferous series. Before describing the widespread Permo-Triassic magmatism, we shall briefly describe this early post-tectonic magmatism.

Carboniferous magmatism

(a) *Plutonism* (Fig. 3, Table I). Mégard (1978) has described the first post-tectonic Eohercynian granite found in Peru: the Pacococha adamellite, in Central Peru. This non-deformed adamellite intrudes the Precambrian and is itself intruded by diabase dykes; it is unconformably covered by the Lower Carboniferous clastics of the Ambo group. The rock is porphyrytic, with large zoned perthites and with biotites which are frequently chloritized. A K/Ar radiometric dating on biotite has given a Late Devonian age: 346 ± 10 m.y. (H. Maluski and P. Blatrix in Mégard, 1978). It seems, therefore, that the Eohercynian tectonic phase occurred somewhat earlier in central Peru than in the Cuzco region where the Amparaes gneiss has an age of 330 m.y.

(b) *Volcanism.* Traces of an acid explosive volcanic activity are present in the various marine or continental sequences of the Permo-Carboniferous.

In the Lower Carboniferous Ambo Group of Central Peru, Mégard (1978) and Dalmayrac (1978) noted both welded and redeposited tuffs intercalated with detrital sediments. The thickness of these tuffs may attain 600 m.

In the Pennsylvanian Tarma Group of southern Peru, green graywackes with volcanic pebbles are interspersed. Laubacher (1978) relates these rocks to a rhyolitic and andesitic volcanic activity.

In the Vilcabamba Cordillera, Von Braun (1967) discovered intercalations of rhyolites in the Lower Permian limestones of the Copacabana Group.

Permo-Triassic magmatism

From the Upper Permian to the Lower Triassic, the Eastern Cordillera was the centre of considerable magmatic activity, that gave the volcanic and volcaniclastic series of the Mitu Group (MacLaughlin, 1924). However, the real extension of Permo-Triassic plutonism has only been recognized during the studies carried out in the past few years in the Eastern Cordillera (Laubacher, 1978; Marocco, 1978; Mégard, 1978) and thanks to several radiometric datings (Capdevila et al., 1977; Lancelot et al., 1978). This magmatism is post-tectonic and it occurred after the Late Hercynian phase (Mégard et al., 1971) dated from the end of the Lower Permian (260–265 m.y.) which brought about a generalized emersion of the Peruvian territory. This phase was characterized by block movements, except in southeastern Peru, where it took the form of a strong but localized folding. Subsequently, throughout the entire Upper Permian and at least part of the Lower Triassic, there was a persistent brittle deformation that occurred in the same areas and at about the same time as the volcanic and plutonic activity.

(a) *Plutonism.* Permo-Triassic intrusions crop out widely in the Eastern Cordillera between 9° and 15°S (Fig. 4). They have been recognized mainly in three regions: to north of Lake Titicaca (Carabaya and Marcapata regions), to the northwest and to the east of Cuzco (Vilcanota, Vilcabamba and Abancay regions), and in central Peru (Tarma–San Ramon and Pampas

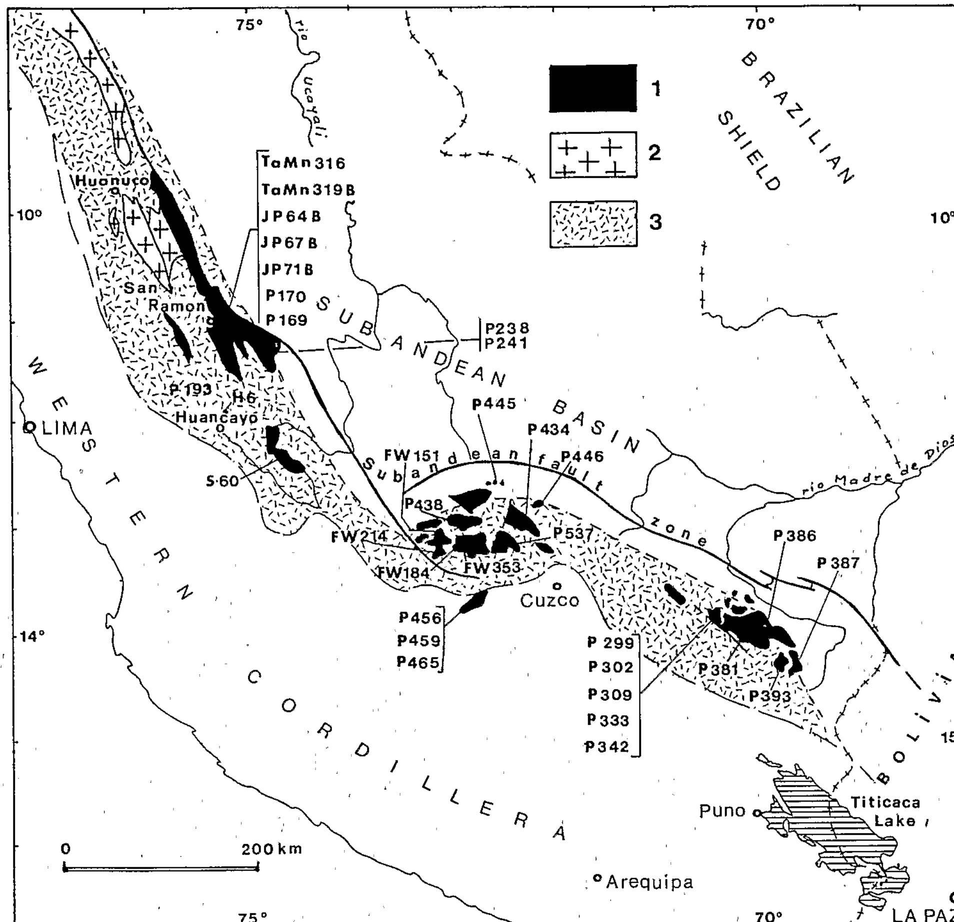

Fig. 4. Upper Permian and Lower Triassic magmatism. *1* = Permo-Triassic intrusions; *2* = composite batholiths including possible Permian plutons; *3* = Permo-Triassic volcanic province. TaMn 316, TaMn319b, JP64b, JP67b, JP71b, P169, P170: granites of San Ramon-La Merced; H6: diorite porphyry of Huancayo; S60: biotite granite of Villa Azul; P537: Machu Picchu granite; P438: Quillabamba adamellite; P381: Coasa granite; P465: Abancay orthogneiss; P393: Aricoma adamellite; P299, P302, P309, P333, P342: Macusani nepheline-syenite.

regions). Very probably there exist other outcrops, particularly in the large composite batholiths which break through the Precambrian east of Cerro and Pasco and north of Huanuco, but there the contacts with the country-rocks do not allow a precise age to be given, and radiometric ages are lacking.

Permo-Triassic plutonism produces batholiths and stocks of variable size, frequently very large, sometimes attaining a length of 50 km and even more in the San Ramon–La Merced Massif. In the Eastern Cordillera their

TABLE II

Major analysis of Eastern Cordillera rocks. All iron calculated in Fe_2O_3. All samples analyzed at CRPG of Nancy (France). See localization of samples in Figs. 4 and 5.

	P 170	P 169	P 193	P 238	P 241	P 342	P 299	P 302	P 309	P 333	P 445	P 497
SiO_2	72.07	74.22	68.26	64.55	65.83	55.71	51.66	50.46	53.01	55.12	50.72	58.89
TiO_2	0.41	0.18	0.62	0.39	0.53	0.65	2.60	2.45	0.57	0.80	0.92	0.55
Al_2O_3	13.51	12.87	14.40	15.90	15.01	19.24	17.17	17.62	21.03	20.80	20.42	17.64
Fe_2O_3 *	2.97	1.96	3.62	5.23	5.21	5.43	9.83	9.30	4.05	3.92	6.20	4.45
FeO	–	–	–	–	–	–	–	–	–	–	–	–
MnO	0.06	0.03	0.04	0.08	0.17	0.21	0.20	0.17	0.14	0.14	0.15	0.13
MgO	0.63	0.08	1.80	0.29	0.45	0.94	3.65	3.39	0.74	0.87	0.74	1.49
CaO	1.12	0.21	0.64	1.00	1.73	1.80	5.62	6.16	1.73	2.48	5.84	5.39
Na_2O	3.82	3.83	2.77	4.23	3.47	8.69	4.84	5.12	9.73	8.95	5.10	4.50
K_2O	4.68	5.01	4.55	6.06	6.39	4.50	3.64	4.08	5.55	4.79	2.62	2.91
P_2O_5	–	–	–	–	–	0.18	–	–	–	0.27	–	–
H_2O^+ H_2O^-	0.89	0.57	1.98	1.35	0.62	0.07 1.78	0.75	0.52	2.23	0.05 0.92	6.21	1.84
TOTAL:	100.16	98.96	98.68	99.08	99.41	99.20	99.96	99.27	98.78	99.11	98.92	97.79
quartz	28.56	32.73	30.65	12.48	15.52							9.36
orthose	27.90	30.11	27.81	36.78	38.37	27.47	21.86	24.61	34.06	28.99	16.69	17.79
albite	32.61	32.96	24.24	36.76	29.83	38.28	29.00	20.66	17.37	31.68	39.42	39.39
anorthite	5.61	1.06	4.31	5.10	6.60	0.20	14.60	13.31	–	2.48	27.08	20.00
diopside	–	–	–	–	1.83	7.63	11.33	14.75	7.53	8.07	3.58	6.29
hypersthene	2.21	0.20	5.99	5.31	4.61							3.83
magnetite	2.20	0.92	2.26	2.24	2.22	2.25	2.22	2.23	–	2.23	2.35	2.26
hematite	–	0.90	–	–	–	–	–	–	–	–	–	–
ilmenite	0.79	0.35	1.22	0.76	1.03	1.28	5.03	4.76	1.13	1.56	1.89	1.08
rutile												–
corindon	0.12	0.78	3.51	0.58	–	–	–	–	–	–	–	–
nepheline						20.43	6.84	12.77	34.06	24.86	3.85	
wollastonite						–	–	–	–	0.12	–	
olivine						2.46	9.11	6.92	1.33	–	5.13	

	P 499	P 177	P 174	P 283	P 279	P 280	P 278	P 230	P 234	P 237	P 227	P 123
SiO_2	62.43	72.40	75.18	76.55	75.33	64.42	67.87	74.05	68.18	75.22	63.15	60.81
TiO_2	0.58	0.39	0.08	0.10	0.15	0.90	0.30	0.15	0.50	0.23	0.66	0.80
Al_2O_3	16.92	13.73	12.71	12.71	13.83	16.34	15.89	14.23	15.56	12.35	17.75	16.54
Fe_2O_3 *	4.32	3.70	2.61	1.35	1.27	6.33	2.63	2.14	3.50	1.61	5.13	6.70
FeO	–	–	–	–	–	–	–	–	–	–	–	–
MnO	0.16	0.05	0.06	0.01	0.02	0.09	0.05	0.04	0.06	0.02	0.07	0.13
MgO	1.40	0.52	0.48	0.09	0.14	1.69	0.19	0.01	0.53	0.35	0.82	3.69
CaO	4.89	4.00	1.78	–	0.37	1.80	1.31	0.22	1.71	0.19	1.90	5.09
Na_2O	4.38	3.39	3.02	3.89	3.44	2.95	4.01	3.81	3.92	3.79	4.09	2.88
K_2O	3.21	1.26	3.24	4.65	4.98	3.56	6.21	5.13	5.37	4.49	5.23	1.42
P_2O_5	–	–	–	–	–	–	–	–	–	–	–	–
H_2O^+ H_2O^-	1.00	0.42	0.65	0.48	0.77	0.98	0.40	0.40	0.47	0.83	1.09	1.50
TOTAL:	99.29	99.86	99.81	99.83	100.30	99.06	98.86	100.40	99.80	99.08	99.89	99.56
quartz	12.65	38.24	40.81	36.22	35.41	25.38	17.87	31.84	19.92	35.69	12.50	19.86
orthose	19.35	7.50	19.33	27.66	29.57	21.55	37.32	30.40	32.01	27.01	31.39	8.60
albite	37.81	28.91	25.81	33.14	29.25	25.57	34.50	32.33	33.46	32.65	35.15	24.99
anorthite	17.37	18.67	8.92	–	1.84	9.15	6.61	1.09	8.56	0.96	9.58	25.84
diopside	6.06	1.11	–	–	–	–	–	–	–	–	–	–
hypersthene	3.40	2.61	1.77	0.23	0.35	9.88	0.72	0.02	2.70	0.89	5.95	15.85
magnetite	2.23	2.20	2.20	–	–	2.24	2.22	1.58	2.20	–	2.22	2.24
hematite	–	–	–	1.36	1.28	–	–	0.42		1.53	–	–
ilmenite	1.13	0.75	0.15	0.02	0.04	1.76	0.58	0.29	0.96	0.26	1.28	1.56
rutile	–	–	–	0.09	0.13	–	–	–	–	0.10	–	–
corindon	–	–	1.01	1.29	2.12	4.47	0.19	2.02	0.19	0.93	1.94	1.06

TABLE II (continued)

	P. 199	P 277	P 261	P 275
SiO_2	75.32	73.32	75.65	66.97
TiO_2	0.39	0.20	0.12	0.45
Al_2O_3	12.93	13.44	12.63	15.68
Fe_2O_3 *	1.60	2.33	1.57	4.75
FeO	–	–	–	–
MnO	0.05	0.05	0.02	0.08
MgO	0.55	0.01	0.06	0.23
CaO	1.04	0.64	0.30	1.38
Na_2O	3.15	3.06	3.39	3.96
K_2O	4.72	5.71	5.44	5.91
P_2O_5	–	–	–	–
H_2O^+ H_2O^-	0.68	0.71	0.44	0.26
TOTAL:	100.43	99.47	99.62	99.67
quartz	35.97	32.70	34.65	16.94
orthose	27.97	34.20	32.42	34.68
albite	26.73	26.24	28.93	33.85
anorthite	5.17	3.22	1.50	6.92
diopside	–	–	–	–
hypersthene	1.37	0.03	0.15	4.17
magnetite	–	2.04	–	2.20
hematite	1.51	0.12	1.52	–
ilmenite	0.30	0.39	0.17	0.87
rutile	0.23	–	0.03	–
corindon	0.75	1.07	0.62	0.37

cumulative surface area is more than 6000 km^2. They cut sharply into the country-rocks where they give rise to a relatively large contact-metamorphic aureole, characterized by andalusite-biotite and biotite-cordierite hornfels which are frequent in the Lower Paleozoic schists. Some of the Permo-Triassic granitoids have undergone tectonic deformations and sometimes are even changed to orthogneiss.

Most of the intrusions have a granitic to granodioritic composition. Varied facies are to be found, but the most frequent is a porphyrytic facies with large, twined orthoclase crystals in a matrix composed of microcline, xenomorphic quartz, plagioclase (An 10-30); the brown biotite of various shades seems to be the ferromagnesian mineral characteristic of Permo-Triassic granitoids. More basic rocks occur in smaller proportions, and they correspond either to initial intrusions forming small stocks and/or inclu-

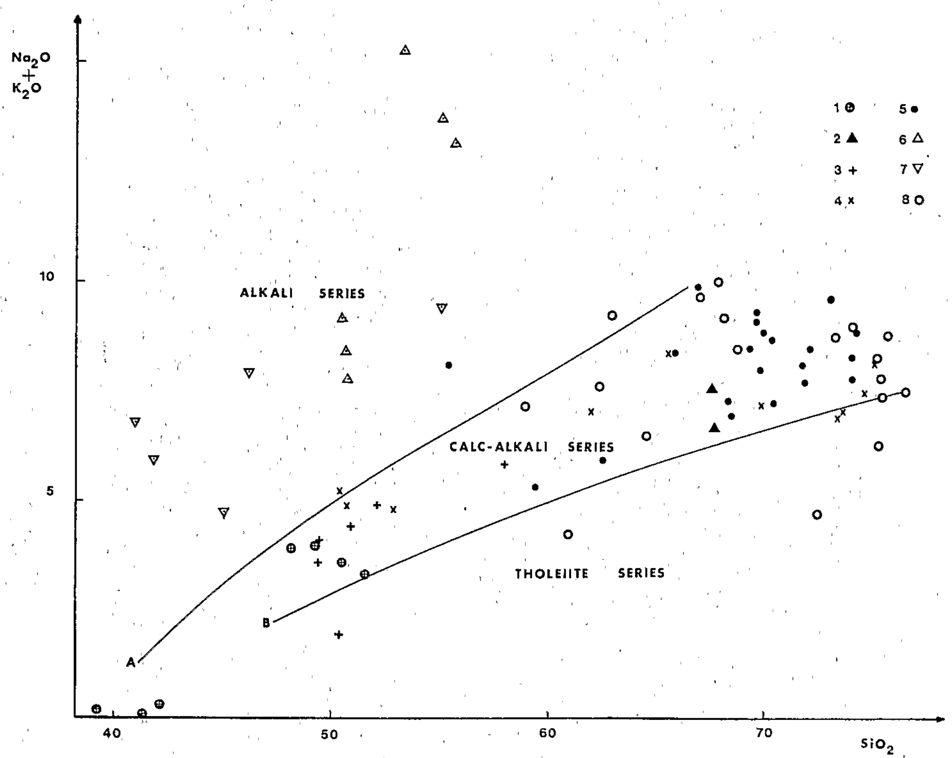

Fig. 5. Alkali/SiO_2 diagram of the Eastern Cordillera magmatism. *A*. Boundary between calc-alkali and alkali series (Irvine and Baragar, 1971); *B*. Boundary between tholeiitic and calcalkali series (Kuno, 1968). *1* = Ultra-mafic precambrian complex; *2* = Precambrian (?) orthogneiss of Marcapata; *3* = Post-tectonic Precambrian magmatism; *4* = Eohercynian magmatism; *5* = Permo-Triassic plutonism; *6* = Nepheline syenite; *7* = Permo-Triassic volcanism; *8* = Andean magmatism.

sions along the outer edges of larger granitic massifs, or to late intrusions of diabasic dykes in the granitoids.

Chemical analyses (Tables I, II), carried out mainly on samples of large batholith's of acid to intermediate composition, seem to identify a calc-alkaline series extremely rich in potassium (Figs. 5 and 6).

By means of field observations (contacts with country-rocks, state of deformation) it has been possible to date relatively some of the intrusions such as the massifs of San Ramon–La Merced and Hualluniyoc in central Peru (Mégard, 1978) and the ones of Quillabamba, Machu Picchu and north-Urubamba in the Cuzco region (Marocco, 1978). Thanks to radiometric datings (Capdevila et al., 1977; Lancelot et al., 1978), some precise ages

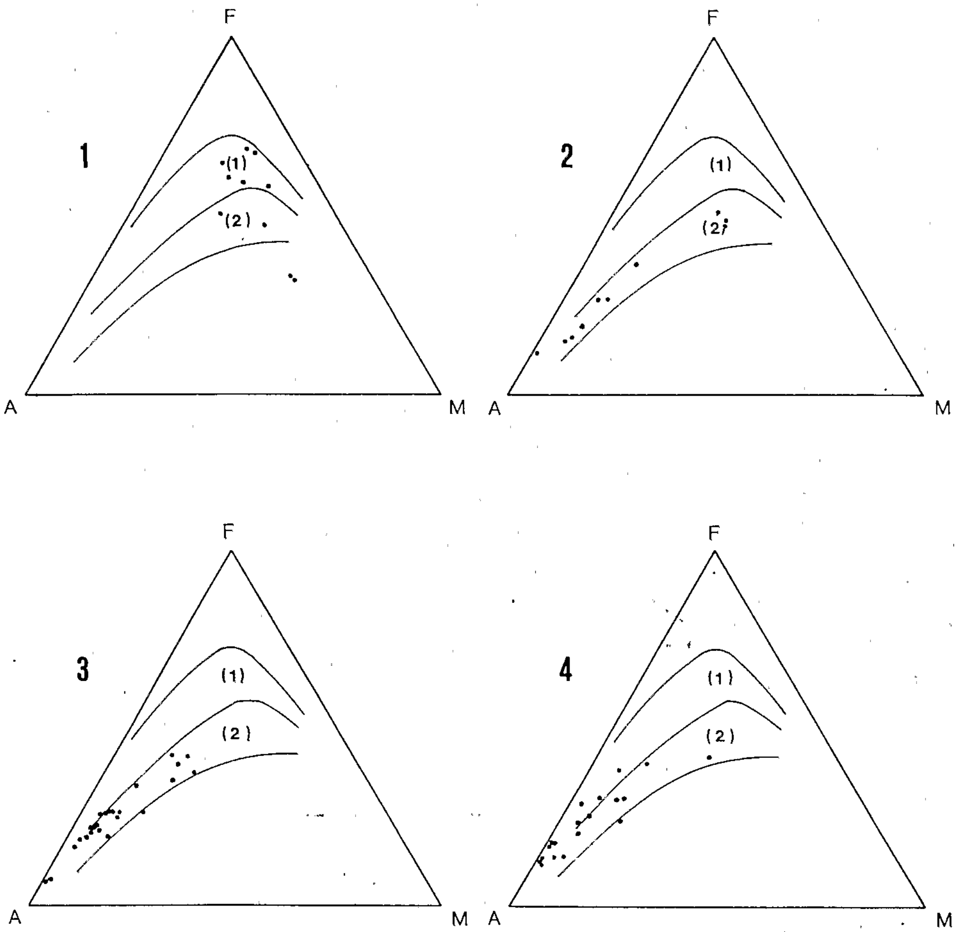

Fig. 6. AFM diagrams of the Eastern Cordillera magmatism. *1* = Precambrian; *2* = Eohercynian; *3* = Permo-Triassic; *4* = Andean. (*1*) Japan tholeiitic series field (Kuno, 1968); (*2*) Japan calc-alkali series field (Kuno, 1968).

have been obtained, that show beyond doubt that the emplacement of Permo-Triassic plutons covered a period of nearly 50 m.y. from the Upper Leonardian to the Anisian (see Table III).

To the plutons described above must be added two intrusions which constitute a special case, namely the Macusani nepheline syenite and the Abancay tectonized intrusive.

The Macusani nepheline-syenite forms a batholith of more than 100 km^2, which crops out to the northeast of Macusani where it constitutes the Allinccapacc (5850 m) and Chichiccapacc (5500 m) peaks. The rock has aphanitic to granular textures, and is of various shades of grey-green, or sometimes rose tinted. It is composed of nepheline, leucite, potassic and sodic feldspars, biotite, barkevikite, aegirine and aegirine-augite and, more seldom, of analcime and sodalite (which sometimes veins the rock) etc. The facies are varied, some being fairly rich in nepheline and ferromagnesians. On its eastern limit the syenite has been strongly fractured "in the solid state" and has acquired a gneissic texture clearly visible to the naked eye. It intrudes into the Mitu Group volcanites, in which layers of phonolite are to

TABLE III

Radiometric dating of Permo-Triassic intrusions of the Eastern Cordillera of Peru

Sample	Age	References
TaMn316, TaMn319B JP64B, JP71B, JP67B	Rb/Sr isochron whole rock 246±11 m.y.	Capdevila et al. (1977)
H6	K/Ar 260±25 m.y.	Rocha Campos and Ameral (1971)
S60	K/Ar 251 m.y.	Stewart et al. (1974)
Machu Picchu granite	Rb/Sr biotite 246±10 m.y.	Priem et al. (published data)
P438	U/Pb zircon 257±3 m.y.	Lancelot et al. (1978)
P381	U/Pb zircon 238±11 m.y.	Lancelot et al. (1978)
Nepheline-syenite of Macusani	K/Ar 180 m.y.	Stewart et al. (1974)
P465	U/Pb zircon 222±7 m.y.	Lancelot et al. (in preparation)
P393	U/Pb zircon 235±3 m.y.	Lancelot et al. (in preparation)

be seen which can be thought to be genetically linked to the syenitic intrusion. If so, it is necessary to envisage a practically simultaneous emplacement of the syenite and the extrusion of Mitu volcanics. A K/Ar dating (Stewart et al., 1974) has given a minimum age of 180 m.y., compatible with our hypothesis.

The Abancay tectonized intrusive (Marocco, 1978) forms a massif of approximately 150 km^2 (13°40′S 72°55′W) and onsists mainly of a medium-grained quartz-diorite containing hornblende and biotite. It is a calc-alkaline rock which is different from the other Permian granitoids by its high sodium and calcium content (Table I). It is deformed at all levels of observation: the quartz is broken and recrystallized while the ferromagnesians are reoriented and define a foliation which is itself refolded. It is therefore a post-tectonic intrusion which has been intensely deformed "in the solid state" after its emplacement. Its relations with the country-rocks are not clear: the Abancay diorite is itself intruded by the Abancay Miocene diorites, whereas the contacts with the sedimentary rocks are faults. A U–Pb dating on zircons has given an age of 222 ± 7 m.y. (J.R. Lancelot, Univ. Montpellier). The deformation that changed the diorite to an orthogneiss is therefore due to a younger tectonism that might be Triassic or Andean in age.

(b) *Volcanism.* At the same time that Permo-Triassic plutons were intruded, the Eastern Cordillera was the centre of an intense volcanic activity, the products of which are widespread between 6° and 16°S. This effusive magmatism generally takes the form of stratiform intercalations within the volcanoclastic molasses of the Mitu Group. Locally form accumulations 2000 to 3000 m thick, suggesting nearby emission zones or even remains of dismantled volcanoes. These accumulations can be observed along the Eastern Cordillera, thereby emphasizing the existence of a Mitu volcanic belt resting upon a Precambrian and Hercynian sialic substratum.

The rocks, tuffs, lapillis and flows of reddish-violet colour, generally are described as being andesites, welded tuffs and basalts. In fact, this is above all a field description, and in thin sections these highly weathered paleovolcanites are rarely identifiable. However, Von Braun's petrographic study (1967) gives an indication of what Vivier et al. (1976) define by means of geochemistry, namely the existence of two incompatible magma-types. One of them now represented by spilitic flows, would seems to have arisen from a deep source, which yielded little-differentiated basalts of a tholeiitic tendency. The other one, much more abundant, is represented by welded tuffs, rhyolites and andesites; it is alkaline and rich in K and would seem to be the manifestation of crustal fusion (Vivier et al., 1976). Peralkaline Permo-Triassic rhyolites (commendites) have also been found between Ayacucho and San Miguel (Noble et al., 1978), as well as olivine basalts. The intercalated phonolites in the Mitu Group to the north of Macusani (Laubacher, 1978) have already been mentioned above. The diagram of Fig. 5 emphasizes the alkaline nature of this volcanism. Andesites are hardly represented at all, but more analyses must be made to confirm this.

The Mitu Group volcanites have not yet been radiometrically dated. However, in central Peru, their stratigraphic position between the Copacabana Group (Lower Leonardian) and the Pucara Group (Ladinian at the base) places them within the Upper Permian to Lower Trias. This attribution is confirmed for the whole of Peru by Permian fauna and flora (Dalmayrac et al., 1977) as well as by the connections of the Mitu Group with several intrusives, radiometrically dated as belonging to the Upper Permian, which are found both in intrusive and pebble from in the Mitu Group.

(c) *The connection between volcanism and plutonism.* The intrusions and the outcrops of Mitu volcanites form a Permo-Triassic magmatic belt which practically coincides with the extension of the Eastern Cordillera. This magmatic province is spread over a length of more than 1000 km in a NNW–SSE direction. There probably exists, therefore, a connection between volcanism and plutonism. This connection could be genetic (crustal fusion) with regard to alkaline volcanism and alkaline (calc-alkaline plutonism). However, a study of the minor elements is necessary to ascertain this. On the other hand, basaltic and tholeiitic magmatism (Vivier et al., 1976), incompatible with alkaline and calc-alkaline magmas, would seem to be linked to the crustal fracturing affecting the Eastern Cordillera which would have promoted its rising from the mantle.

(d) *The connection between fracturing and magmatism.* During the Permo-Trias phase, a fracturing, given rise to reliefs, affected the Eastern Cordillera. One of the forms taken by this fracturing is that of large faults, generally longitudinal and bordering the Mitu basins. The Mitu volcanism is localized along these faults: this is the case near Carhuamayo (Mégard, 1978) and at Pomacancha (Paredes, 1972), on the southwest edge of the Vilcabamba Cordillera (Marocco, 1978), at Sicuani (Audebaud, 1967) and to the north of Lake Titicaca near Macusani (Laubacher, 1978). It is more difficult to recognize a direct link between the Permo-Triassic fracturing and the emplacement of granitoids of the same date.

ANDEAN MAGMATISM

Andean magmatism (Fig. 7) synchronous with Andean sedimentation is practically unknown in the Eastern Cordillera where it is to be found only, in a few cinerite or tuff intercalations in the limestones of the Triassic and Lower Jurassic.

No typical "syntectonic" Andean intrusives are known, but it must be noted that a Hercynian or Precambrian age has been systematically, and

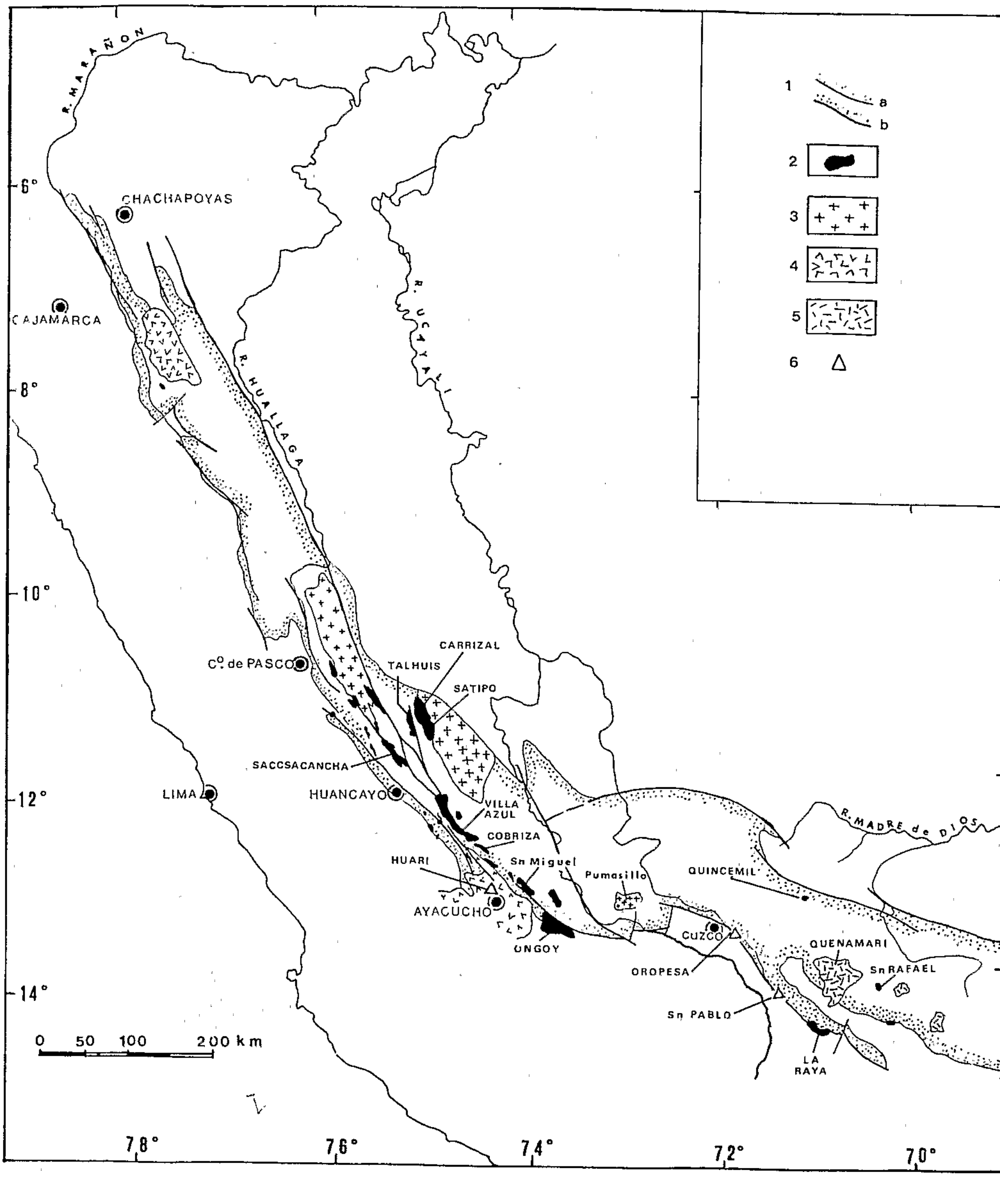

Fig. 7. Andean magmatism of the Eastern Cordillera of Peru. *1* = limits of the Eastern Cordillera, (*a*) faulted limit; (*b*) non-faulted limit; *2* = circumscribed Andean intrusions; *3* = composite batholith including possible Andean intrusions; *4* = folded Cenozoic volcanic formations; *5* = unfolded Pliocene pyroclastic formations; *6* = shoshonitic Plio-Quaternary volcanoes.

perhaps wrongly, attributed to all the heavily deformed igneous rocks known in the composite batholiths of the Eastern Cordillera. There remain, therefore, clearly intrusive, circumscribed plutonic massifs, and unconformable late volcanic formations.

The majority of these Andean age igneous rocks are localized in central Peru. As regards the intrusive rocks, this age is attributed to them because they cut through either Meso-Cenozoic formations or formations of Upper Paleozoic age, which were deformed during the Andean tectogenesis. Non-deformed granitoids present in the large complex batholiths such as those of Huachon or Satipo, have also been attributed to the Andean cycle by Mégard (1978). The Andean volcanic formations, sometimes folded themselves, are recognizable by the strong unconformity which separates them from the Mesozoic or Upper Paleozoic substratum on which they lie; these formations are seldom in the Eastern Cordillera.

Andean plutonism in the Eastern Cordillera of Peru

Plutonism in Central Peru. In the Eastern Cordillera of Peru, the Mesozoic formations affected by Andean tectonism are known only in the form of synclinoria or fault blocks. In spite of frequent sedimentation hiatuses, these formations most often lie without a clear angular unconformity over Upper Paleozoic series. The unconformity noted by Mégard (1978) near 11°S between the Triassic limestones and the Upper Permian red beds, is not strongly marked. For this reason, the relatively intense folding, frequently accompagnied by cleavage, which affects the Upper Paleozoic and, where present, its Mesozoic cover, is considered by this author to be an Andean age. Since these folds are locally covered by unconformable red beds dated from the latest Cretaceous near their base, the folding can even be attributed to the "Peruvian phase" of Late Cretaceous age. Consequently, the plutonic rocks intruding the folded upper Paleozoic are considered as Andean and more exactly, of uppermost or more recent Cretaceous age.

Most of the Andean intrusives are homogeneous in composition. This is the case of the ophitic microdiorites which crop out in dykes, sills and plugs in the Ricran synclinorium between 11°15′ and 12°45′S. Their maximum dimension is never more than 1 km; they intrude into the complex structures which affect the Upper Paleozoic and Mesozoic in this syclinorium.

Plugs of 1–5 km in diameter have been mapped out by Guizado and Landa (1965) and by Narvaez and Guevara (1968) between 12° and 13°S. Most of them are of a dioritic to tonalitic composition; some of them are grabbroic. According to these autors, some of these intrusives crosscut faults which moved during the Miocene phase. These intrusion would be, therefore, of Miocene or Pliocene age, which is also the case of numerous plugs in the northeastern part of the Western Cordillera, often linked to mineralisations.

Towards 12°40′S, subvolcanic plugs have been observed by Mégard and Paredes (unpublished) along the southwestern edge of the Eastern Cordillera at the eastern limit of the Ayacucho Basin. This plugs are intrusive in rocks of Upper Paleozoic and Miocene age; their texture is porphyritic in the center and vitreous at the walls, and their composition is rhyolitic to dacitic. An unpublished K/Ar dating by Noble, McKee and Mégard fixes the age of one of these plugs in the Lower Miocene.

Between 11°30′ and 13°30′S occur stocks of 5–50 km in length and 2–10 km in width, mostly granitic and generally elongated in a NW–SE-direction. All of them intrude Pennsylvanian or Permian formations, and one of them is overlain by unconformable red beds similar to those of Tambo which yielded charophyte oogones of latest Cretaceous age (Mégard, 1978). For this reason, this author relates these granites to the Late Cretaceous phase. Among this stocks, those of Villa Azul and Cobriza show special characteristics. Both are stratiform, in part at least, and were emplaced within country-rocks dating partly from the Pennsylvanian and Early Permian in which they give rise to a clear contact metamorphism: andalusite is a common mineral and in the Cobriza mine a limestone bed, intercalated in the slates and laminated sandstones of the Pennsylvanian, has been changed into a marble rich in garnet, diopside, actinote, epidote and scapolite; this marble was subsequently the location of a pyrrhotite and chalcopyrite mineralisation. The Villa Azul biotite granite forms one of the largest stock. Its connections with the country rocks furnish apparently solid arguments in favor of an Andean age: its southern extremity cuts sharply the axes of Andean folds affecting the Upper Paleozoic (Narvaez and Guevara, 1968) and, according to Guizado and Landa (1965), this granite is probably intrusive in Triassic and Lower Jurassic Limestones; it is covered by unconformable conglomerates which are very probably Neogene in age. However, Stewart et al. (1974) give a K/Ar age of 251 m.y. to this stock; if this date were to be confirmed, it would certainly be necessary to consider this pluton as a composite stock including Hercynian and Andean elements. Further north, toward 11°30′S, the Carrizal leucogranite also cuts Andean folds which affect the Upper Paleozoic.

Apart from this massifs, at first sight of a very homogeneous nature, more complex intrusive bodies are known, composed of early dioritic gabbroic elements, intruded by adamellites, tonalites or leucogranites, which are themselves sometimes intruded by late porphyritic rhyolites. This is the case of the Sacsacancha and Talhuis stocks that Paredes (1972) mapped between 11°30′ and 12°S

Besides this plutons it is probable that certain parts of the large composite batholites of Huachon and Satipo (Fig. 7) are of Andean age. According to Mégard (1978), this would seem to be in particular the case of certain sheet granite, settled in open cracks along NW–SE Andean faults in the southern part of the Huachon batholith, and also of the Mariposa leucogranite, part and parcel of the Satipo batholith which, apart from its finer texture is very similar to that of Carrizal.

Andean plutonism in northern and southern Peru. Andean-age plutons are rare in the Eastern Cordillera of northern and southern Peru.

In the north, there are practically no examples of them, apart from a small granitoid stock near Buldibuyo (8°02′S) mentioned by Wilson and Reyes (1964).

In the south, they are slightly more numerous, but it is not easy to deduce their age from their relations with the country-rocks which for the most part are composed of Paleozoic series folded either by the Eohercynian phase or by the Late Hercynian phase which is represented by genuine folding to the north of the Lake Titicaca (Audebaud and Laubacher, 1969). Laubacher (1978) mentions several plugs of Andean age which intrude into rocks of Permian or more recent age. The largest is the granitic plug of San Francisco (also called San Rafael) to which a tin mineralisation is linked, and to which Laubacher (1978) had attributed a Cenozoic age. The K/Ar datings carried out by Clark et al. (1982) show that the intrusion and the mineralisation date from the Upper Oligocene phase, and that the same is true for a nearby plug close to Nuñoa.

Laubacher (1978) mentions as well a few dioritic plugs which intrude into the Upper Permian redbeds, which themselves lie unconformably on the Late Hercynian folds. For their part, Audebaud et al. (1979) mention a small gabbroic massif near Quincemil dated at 26 m.y. by the K/Ar method. Finally, according to most of the geological maps, the La Raya granitoids intrude into Hercynian and Andean rocks and are therefore probably Andean.

In addition to these circumscribed intrusions, we shall note that according to Marocco (1978), the northwestern part of the Pumasillo batholith cuts faults which affect the latest Cretaceous redbeds. This batholith, most part of which is Upper Permian, would seem therefore to be composite, and to include granites of a Cenozoic age.

Conclusions on Andean plutonism. The Andean plutonism of the Eastern Cordillera of Peru is therefore, for the most part, limited to central Peru and more precisely to a zone where the Late Cretaceous phase plays a predominant role.

Besides this, the existence in the Eastern Cordillera and the northeastern part of the central-Peruvian high plateaus of this longitudinal "island" where deformation was intense during the Late Cretaceous phase, and where

Andean plutonism is widespread, poses problems in so far as this "island" is isolated far to the northeast of the Coastal Zone, long considered as the region to have been deformed at this epoch.

With regard to magmatism, it can certainly be noted (cf. Mégard, 1978) that the amount of K_2O contained in the plutons related to the Late Cretaceous phase increases from the coastal batholith towards the Eastern Cordillera, and they can be globally linked to the same subduction zone, but this is only a hypothesis.

Andean volcanism

Only very exceptionally is the locus of widespread volcanism. Deformed Tertiary volcanites, very probably Pliocene in age, are only known of between 7° and 8°S in northern Peru where Wilson and Reyes (1964) describe dacitic and rhyolitic tuffs. This serie is 1500 m thick and is isolated in relation to the large extension of volcanic rocks situated near Cajamarca 100 km farther west-northwest, or around Otuzco, the same distance away in a west-southwest direction. They could possibly be the easternmost elements of the volcanic arc which was active at the western edge of the South American continent during the Oligocene and Miocene; their composition, at a first approximation calc-alcaline, fits in with this hypothesis.

In the Ayacucho region of central Peru, towards 13°S, the folded Miocene volcanic rocks stretch broadly east and cover unconformably the westernmost structural units of the Eastern Cordillera.

In southern Peru, where the belt is much wider, the pre-Pliocene volcanic series are confined to the Western Cordillera and the Altiplano.

On the other hand, flows of rhyolitic welded tuffs are known in the south, in particular at Quenamari, where they lie, at some places, on top of vesicular basalts (cf. Laubacher, 1978). This tuffs have been dated by the fission track method at 4.2 m.y. by Barnes and al. (1970). These Pliocene tuffs are tilted at some places.

Three outcrops of quartz latites must also be mentioned. They are situated along the southwestern edge of the Eastern Cordillera between 13° and 14°30′S and lie along longitudinal faults. Among them the Huari quartz-latites have been dated at 3.7 ± 0.4 m.y. by the K/Ar method (Noble et al., 1975). These are isolated outcrops of a K_2O-rich volcanism that may be called shoshonitic, and which extends to the northeast of the zone occupied by the Plio-Quaternary calc-alcaline series (Lefèvre, 1973).

CONCLUSIONS

Although considerable progress has been made during the last 10 years, our knowledge of magmatism in the Eastern Cordillera is still incomplete.

This paper constitutes a revue of past studies, but also provides a certain number of new data, particulary in the fields of geochemistry and geochronology. However, it is necessary to state that, although the field studies carried out on connections between the various magmatic groups, are beginning to be relatively established, on the other hand the geochronological, petrological and geochemical data are still insufficient, especially as regards to the minor elements.

With regard to the Precambrian orogeny, the relative chronology of the magmatic groups has been established mainly in the Huanuco region. In order to confirm the evolution put forward, it is necessary now to go into the study of this evolution more deeply in other zones of the Eastern Cordillera. In particular, one should investigate more precisely the chemical nature and genesis of synsedimentary volcanic series and ultrabasic rocks, and date the recognized groups radiometrically.

Hercynian magmatism is now quite well characterized, both in the field and by relatively numerous chemical and radiometric data.

There is little Andean magmatism in the Eastern Cordillera except in central Peru, in a zone which coincides with the one where the Late Cretaceous phase is found. However, its characteristics are not well known.

In conclusion, therefore, in the Eastern Cordillera the Precambrian, Hercynian and Andean magmatisms show important differences: ultrabasic rocks exist only in the Precambrian; Hercynian magmatism of which there are abundant examples in the Eastern Cordillera, seems to be linked to a thinning and "rifting" of the sialic crust on which the Hercynian chain was lying (Dalmayrac et al., 1977) rather than an active margin (Helwig, 1972) as seems proved for Andean magmatism. However, these differences are barely apparent where the chemical nature is concerned, for the analyses at our disposal are only of major elements and incomplete magmatic sequences. They establish only the fact that the three cycles are characterized by calc-alkaline series. Only a study of the minor elements and isotopic relationships would make it possible to distinguish between them and to propose hypotheses on the nature and origin of each magmatic group.

ACKNOWLEDGEMENTS

This paper is the result of studies carried out within the framework of a joint ORSTOM (France)-INGEMMET (Peru) project. It has also benefited from the scientific and financial aid of the "Centre National de la Recherche Scientifique" (R.C.P. 132), the "Institut Français d'Etudes Andines" and of the Pontificia Universidad Catolica del Peru. The chemical analyses were carried out at the "Centre de Recherches Petrographiques et Géochimiques of Nancy and at the "Centre Armoricain d'Etudes Structurales des Socles of

Rennes (France). The help of R. Capdevila and J.P. Bard in the petrological identification of intrusive and metamorphic rocks is gratefully acknowledged.

REFERENCES

Audebaud, E., 1967. Etude géoloqique de la région Sicuani-Ocongate (Cordillere Orientale du sud péruvien). Thèse 3° cycle, Univ. Grenoble.

Audebaud, E., Bernard, D., Vatin-Pérignon, N. and Vivier, G., 1979. Quelques âges K/Ar sur des roches ignées cénozoïques du sud et péruvien. Conséquences géodynamiques. Réunion Ann. Sci. Terre.

Audebaud, E. and Laubacher, G., 1969. Sur une discordance tardi-hercynienne dans la Cordillère orientale du sud du Pérou. C.R.A. Sci. Ser. D, 269; 2163–2166.

Aumaître, R., Grandin, G. and Guillon, J.H., 1977. Données lithologiques et structurales relatives à un bloc précambrien surélevé de la Cordillère andine orientale (Pérou central). Les corps de roches ultrabasiques qui y sont présents. Bull. Soc. Géol. Fr., 19 (5).

Bard, J.P., Botello, R., Martinez, C. and Subieta, T., 1974. Relations entre tectonique, métamorphisme et mise en place d'un granite éohercynien à 2 micas dans la Cordillère real de Bolivie (Massif de Zongo-Yani). Cah. ORSTOM, Ser. Géol., 6 (1).

Barnes, V.E., Edwards, G., Mc. Lauglin, W.A., Friedman, I. and Joensuu, O., 1970. Macusanite occurence, age and composition, Macusani Peru. Geol. Soc. Am. Bull., 81 (5); 1539–1546.

Beaufils, G., Henry, B. and Huaman, A., 1982. Las formaciones precámbricas ultrabásicas de los Andes orientales y las mineralizaciones cuproniquelíferas asociadas: el macizo de "San Luis" (Chinchao). IV Congr. Peruano Geol., Lima, 1978 (in press).

Capdevila, R., Mégard, F., Paredes, J. and Vidal, Ph., 1977. Le batholite de San Ramon (Cordillère orientale du Pérou central), un granite tardihercynien mis en place à la limite Permien-Trias. Données géologiques et radiométriques. Geol. Rundsch., 67 (2).

Clark, A., Archibald, D. and Palma, V., 1982. Andean granites in the Carabaya Cordillera, southern Peru. Queen's Univ., Kingston, Ont. (in press).

Dalmayrac, B., 1978. Géologie de la Cordillère orientale de la région de Huanuco: sa place dans une transversale des Andes du Pérou central (9°S à 10°30'S). Trav. Doc. ORSTOM, 93: 181 p.

Dalmayrac, B., Laubacher, G. and Marocco, R., 1977. Caractères généraux de l'évolution géologique des Andes péruviennes. Thèse Doctorat, Univ. Montpellier.

Frankl, E.J., 1958. The Limbo formation. Conv. Bol. Tecn. Petrol., La Paz.

Fricker, P. and Weibel, M., 1960. Zur Kenntnis der Eruptivegesteine in der Cordillera Vilcabamba (Peru). Schweiz. Mineral. Petrogr. Mitt., 40 (2): 359–382.

Grandin, G., Mendoza, J., Miranda, C. and Porras, C., 1982. Estudio petrográfico de la serie metamórfica precámbrica y de las rocas igneas asociadas en el área de Huancapallac (Huanuco). IV Congr. Peru Geol., Lima, 1978.

Grandin, G. and Zegarra, 1979. Las rocas ultrabásicas en el Perú. Las intrusiones lenticularas y los sills de la región de Huánuco-Monzon. Bol. Soc. Geol. Perú, 63: 99–116.

Guizado, J. and Landa, C., 1965. Geologia del cuadrángulo de Pampas. Com. Carta Geol. Nac. Bol, 12.

Harrison, J.V., 1951. Geologia de los Andes Orientales del Perú Central. Bol. Soc. Geol. Peru, 21: 97 pp.

Helwig, J., 1972. Cate Paleozoic stratigraphy and tectonics of the Central Andes. Symp. Intn. sobre os sistemas carboniferos e permianos na America do Sul. An. Acad. Bras. Cienc., 44 (Suplo.), pp. 161–171.

Irvine, T.N. and Baragae, W.R.A., 1971. A guide to the quimical classification of the common volcanic rocks. Can. J. Earth. Sci., 8: 523–548.

Kuno, H., 1968. Differenciation of Basaltic Magmas. In H.H. Hess and A. Poldervaart (Editors), Basalts, 2. Intersciences. New York, NY., pp. 623–688.
Lancelot, J.R., Laubacher, G., Marocco, R. and Renaud, U., 1978. U/Pb radiochronology of two granitic plutons from the Eastern Cordillera (Peru). Extent of Permian magmatic activity and consequences. Geol. Rundsch., 67 (1).
Laubacher, G., 1978. Géologie de la Cordillère orientale et de l'Altiplano au nord et nord-ouest du Lac Titicaca (Pérou). Trav. Doc. ORSTOM, 95: 191 pp.
Lefèvre, C., 1973. Les caractères magmatiques du volcanisme plioquaternaire des Andes dans le Sud de Pérou. Contrib. Mineral. Petrogr., 41: 259–272.
MacLaughlin, D.H., 1924. Geology and physiography of the Peruvian Cordillera, Departments of Junin and Lima. Geol. Soc. Am. Bull., 35: 591–632.
Marocco, R., 1978. Un segment est-ouest de la chaîne des Andes péruviennes: la déflexion d'Abancay. Trav. Doc. ORSTOM, 94: 195 pp.
Marocco, R. and Garcia Zabaleta, F., 1974. Estudio geológico de la región entre Cuzco y Machu Picchu. Bull. Inst. Fr. Etud. Andines, 3 (2): 1–27.
Martin, C. et Paredes, J., 1977. Données nouvelles sur le Paléozoique de la zone subandine du Pérou central. C.R. Acad. Sc. Paris, t. 284, série D, pp. 1647–1650.
Mégard, F., 1967. Commentaire d'une coupe schématique à travers les Andes centrales du Pérou. Rev. Geogr. Phys. Géol. Dyn., 9 (4): 335–346.
Mégard, F., 1978. Etude géologique des Andes du Pérou Central: contribution à l'étude des Andes, 1. Mém. ORSTOM, 86: 310 pp.
Mégard, F., Dalmayrac, B., Laubacher, G., Marocco, R., Martinez, C., Paredes, J. and Tomasi, P., 1971. La chaîne hercynienne du Pérou et en Bolivie. Premiers résultats. Cahiers ORSTOM. Ser. Géol., 3 (1): 5–44.
Narvaez, S. and Guevara, C., 1968. Mapa geológico del cuadrángulo de Huancavelica al 1/100000. Com. Čarta Geol. Nac., Lima.
Noble, D.C. Bowman, H.R., Hebert, A.J., Silberman, M.L., Heropoulos, C.E., Fabbi, B.P. and Hedge, C.E., 1975. Chemical and isotopic constraints and the origin of low-silica latite and andesite from the Andes of Peru. Geology, 3: 501–504.
Noble, D.C., Silberman, M.L., Mégard, F. and Bowman, H., 1978. Commendite (peralkaline rhyoloite) and basalt in the Mitu Group, Peru: evidence for Peruvian Triassic lithospheric extension in the Central Andes. J. Res. U.S. Geol. Surv., 6 (4) 453–457.
Paredes, J., 1972. Etude géologique de la feuille de Jauja au 1/100000 (Andes du Pérou central), Thèse 3e cycle, USTL, Montpellier.
Rocha-Campos, A.C. and Amaral, G., 1970. K/Ar ages of igneous rocks of the Mitu Group, Huancayo region, Central Peru. Bol. Paranense Geocienc., 28–29: 3–7.
Steinmann, G., 1929. Geologie von Peru. Karl Winter, Heidelberg, 448 pp.
Stewart, J.W., Evernden, J.F. and Snelling, M.J., 1974. Age determinations from Andean Peru. A reconnaissance survey. Geol. Soc. Am. Bull., 85: 107–116.
Turner, J.C.M., 1970. The Andes of northwestern Argentina. Geol. Rundsch., 59 (3).
Vivier, G., Audebaud, E. and Vatin-Pérignon, N., 1976. Le magmatisme tardi-hercynien et andin le long d'une transversale sud-péruvienne; bilan géochimique des éléments incompatibles. Reunion Annu. Sci. Terre, Paris.
Von Braun, E., 1967. Geologie und Lagerstätten im Gebiet von Vilcabamba (S. Peru) Geol. Jahrb., 84, 215–260.
Wilson, J.J. and Reyes, L., 1964. Geología del cuadrángulo de Pataz. Bol. Com. Carta Geol. Nac, 9.
Wilson, J.J., Reyes, L. and Garayar, J., 1967. Geología de los cuadrángulos de Mollebamba, Tayabamba, Huayles, Pomabamba, Carhuaz y Huari. Serv. Geol. Min. Bol., 16.

[Accepted for publication April 8, 1981]