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GEOCHRONOLOGICAL AND GEOCHEMICAL INVESTIGATIONS ON PLUTONIC ROCKS FROM THE COMPLEX OF PUERTO VALLARTA, SIERRA MADRE DEL SUR

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RESUMEN

En la Sierra Madre del Sur (México) se han identificado nueve complejos intrusivos cuya composición varía de trondjemítica a granítica (Negendank *et al.*, 1985). Con base en datos estratigráficos y en menor grado radiométricos, se puede deducir que la edad de estos complejos varía del Jurásico al Cenozoico. El objeto de este estudio es determinar las edades de intrusión y de enfriamiento de los granitos del complejo de Puerto Vallarta y, asimismo, aclarar el origen del magma.

Se han efectuado mediciones isotópicas de Rb-Sr y K-Ar en rocas totales y minerales, obteniéndose los siguientes resultados:

- La edad de intrusión de los granitos del complejo Puerto Vallarta está limitada entre 97 ± 3 Ma y 88 ± 2 Ma.
- La edad de enfriamiento de la biotita es 83 ± 3 Ma para el sistema Rb-Sr y la edad de enfriamiento de la hornblenda es 86 ± 2 Ma para el K-Ar.
- Durante el período de 100 Ma a 80 Ma, la velocidad de enfriamiento del complejo Puerto Vallarta es de aproximadamente 35°C por 1 Ma.
- Los granitos (con 87Sr/86Sr inicial = 0.704 - 0.706) se originaron en el Manto Superior y se contaminaron sólo en menor grado por el estroncio cortical.
- Los xenolitos básicos y el magma encajonante no son comagmáticos.

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ABSTRACT

Within the Sierra Madre del Sur nine intrusive complexes, varying in composition from trondjemitic to granitic, have been identified by Negendank *et al.* (1985). The age of the complexes, based on stratigraphic and to a limited extent on radiometric data, ranges from Jurassic to Cenozoic.

In order to determine the age of intrusion and cooling of the granitoids of the complex of Puerto Vallarta and to shed some light on the origin of the respective melts Rb-Sr and K-Ar whole-rock and mineral measurements have been carried out. The results obtained are:

- The intrusion age of the granitoid is limited between 97 ± 3 Ma and 88 ± 2 Ma, the biotite cooling age is 83 ± 3 Ma for the Rb-Sr system. The hornblende cooling age is 86 ± 2 Ma for the K-Ar system,
- the cooling rate of the complex of Puerto Vallarta in the interval from about 100 Ma to about 80 Ma is approximately 35°C per 1 Ma,
- the granitoids have 87Sr/86Sr-initial ratios between 0.704 and 0.706, which indicate a possible mantle origin,
- basic xenoliths and the surrounding granitoids are derived from different sources.

INTRODUCTION AND GEOLOGY

The plutonic complex of Puerto Vallarta constitutes the northwestern part of the Sierra Madre del Sur, a geologically quite complicated mountain range between the Trans Mexican Volcanic Belt and the Pacific coast that formed during the Mesozoic and Early Cenozoic time. It appears to represent the southern prolongation of the Sierra Madre Occidental. The plutonic complexes between Puerto Vallarta and Acapulco are possibly of Cretaceous to Tertiary age, volcanoclastics belong to the Late Cretaceous and the volcanics belong to Eocene - Oligocene. Granitoids and volcanics are under investigation at the moment in order to obtain information on the magmatic activity within this region from Mesozoic through Cenozoic up to now. Along three profiles (Fig. 1) the following geological sequence can be observed from base to top:

1. Cretaceous - Tertiary granitoids, occasionally intruded into
2. a metamorphic frame (Jurassic),
3. folded limestones of Lower and Middle Cretaceous age, with volcanoclastic series starting during the Tithonian (Campa and Coney, 1983).
4. Upper Cretaceous volcanics,
5. continental molasse, grupo Balsos,
6. Eocene - Oligocene ignimbrites and volcanics with calcalkaline and to a minor extent trachyandesitic character,

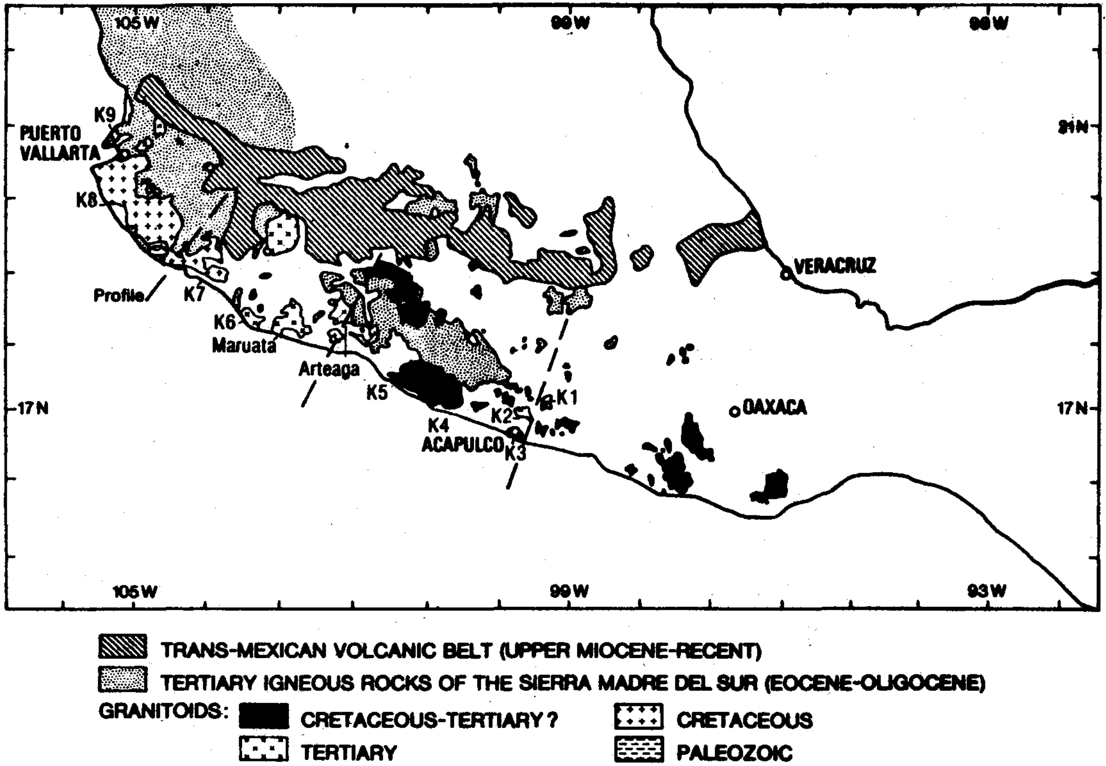

Fig. 1. The granitoid complexes in the Sierra Madre del Sur, Mexico.

7. Upper Miocene - Recent volcanism of the TMVB.

Paleomagnetic results for three plutonic complexes, for the granites of Acapulco, Xaltianguis and Ocotito (Urrutia-Fucugauchi *et al.*, 1984; Negendank *et al.*, 1987; Böhnel *et al.*, 1988) suggest that "the intrusives have not been affected by any major tectonic movements since the time of acquisition of the paleomagnetic record. The Xolapa terrane was accreted to the southern Mexico margin before the early Tertiary." Fig. 2 is a geological map based on an old compilation from CETENAL for the investigated complex of Puerto Vallarta and shows the sample locations.

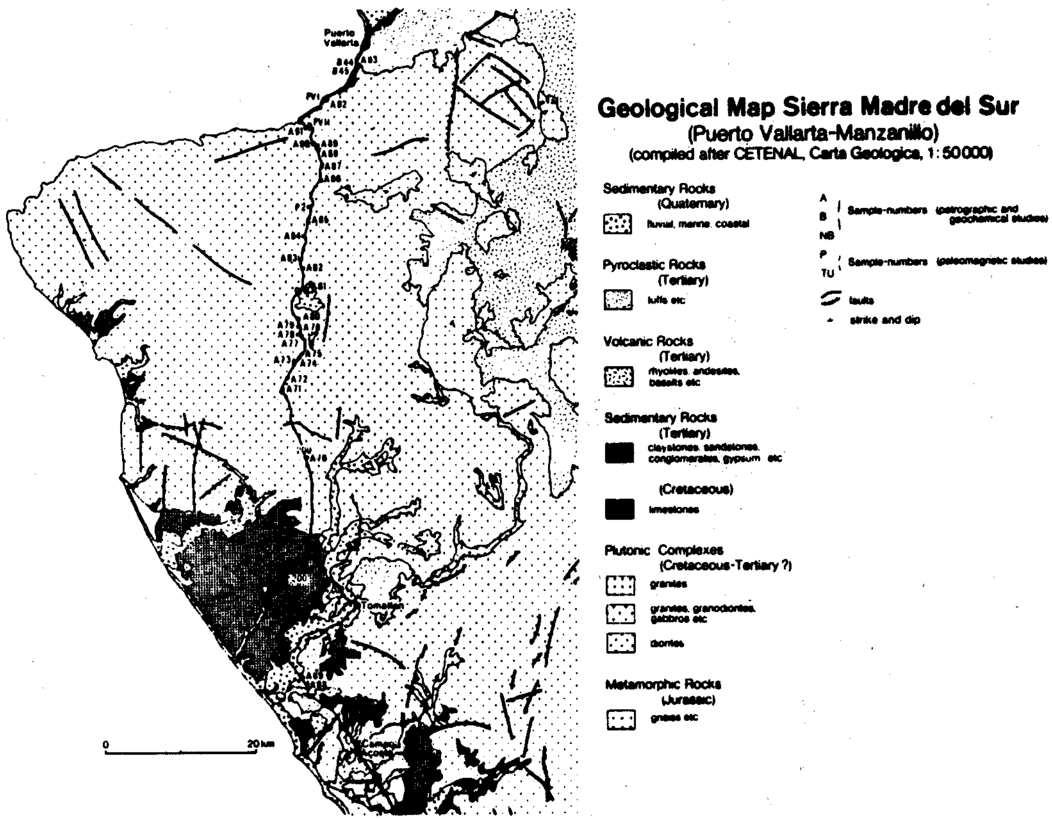

Fig. 2. Distribution of sample localities within the complex of Puerto Vallarta. This map is used to give an overview of our sample locations. In the meantime new results have revealed different ages for the volcanic rocks in the north and for sedimentary rocks in the south and southwest.

PETROLOGICAL AND GEOCHEMICAL ASPECTS OF THE GRANITOIDS OF THE SIERRA MADRE DEL SUR

All plutonic bodies (Punta Mita (K 9), Puerto Vallarta - Manzanillo (K 8), Manzanillo (K 7), Arteaga and Punta San Telmo (K 6), Nuxco - Petatlán (K 5), Atoyac de Alvarez (K 4), Acapulco (K 3), Xaltianguis (K 2), Tierra Colorada/Ocotito (K 1) range in composition from gabbros through tonalites (diorites) and granodiorites to granites (Fig. 3) (Fiala *et al.*, 1982; Negendank, 1987; Negendank *et al.*, 1987a, b).

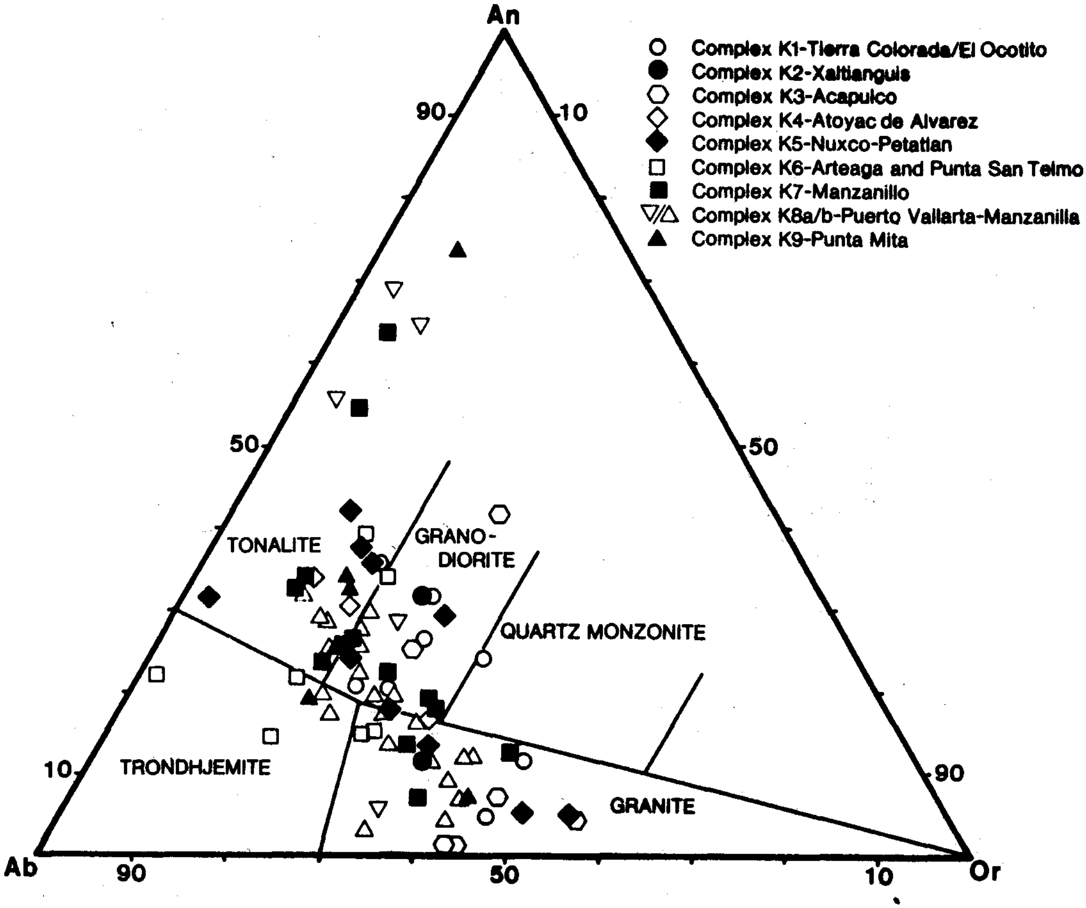

Fig. 3. Classification of Quartz-rich plutonic rocks according to O'Connor (1965).

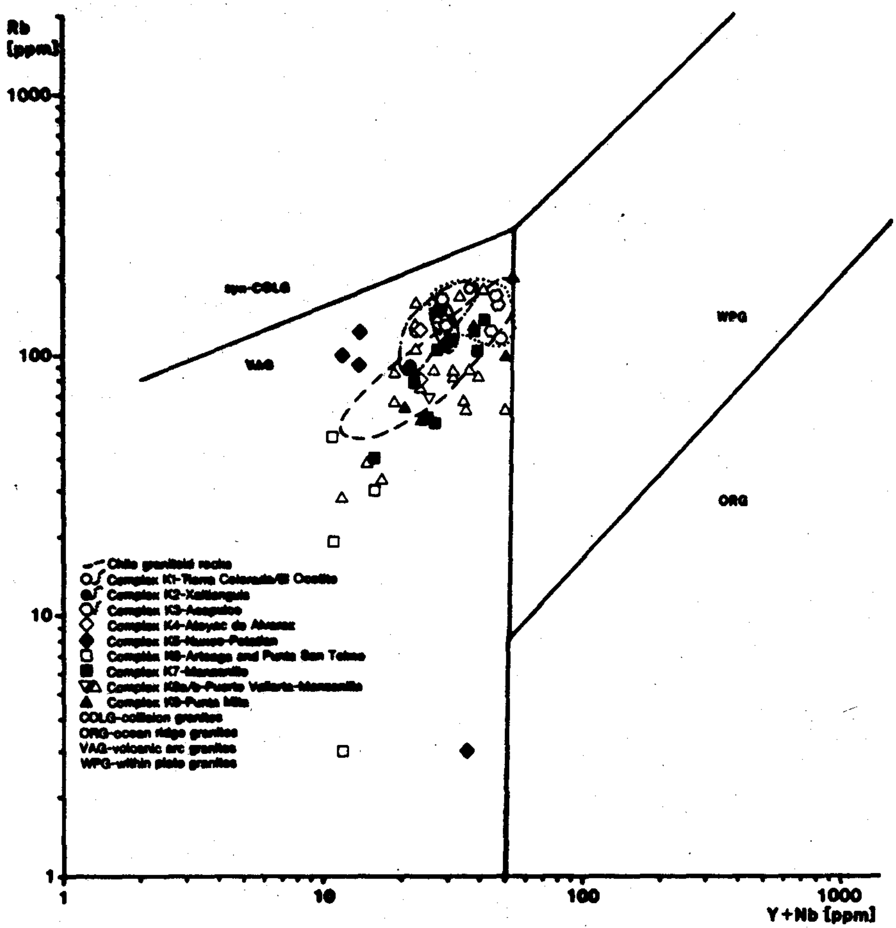

Fig. 4. Diagram Rb/Y+ Nb according to Pearce *et al.*, 1984, classification of the granitoids as Volcanic Arc Granites (VAG).

The detailed petrographic study will be published elsewhere. According to Chappel and White (1974) they classify as I-type granites, have a calcalkaline character and contain biotite ± hornblende as the dominant ferromagnesian minerals. In addition, they bear magnetite and titanomagnetite (with secondary oxidation) in varying amounts as phases of the system TiO_2 - FeO - Fe_2O_3. In general, ilmenite occurs only subordinately or is not at all present (Magnetite series of Takahashi *et al.*, 1980).

The diagram Rb/Y+Nb according to Pearce *et al.* (1984) (Fig. 4) suggests that these rocks resemble granite occurrences from Chile belonging to "Volcanic arc granites" and intruded at an *active continental margin.*

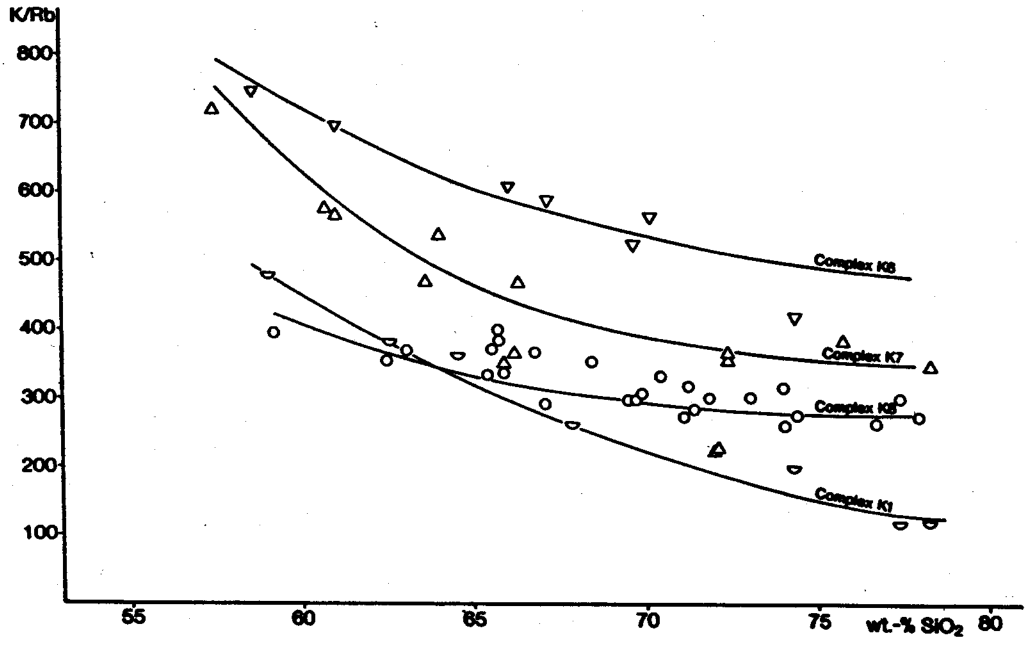

Fig. 5a. K/Rb - SiO_2 diagram showing the individual chemical evolution of each of the complexes.

Samples of nine granitic plutons between Puerto Vallarta and Acapulco have been analysed for major and many of the large ion lithophile (LIL) and high field strength

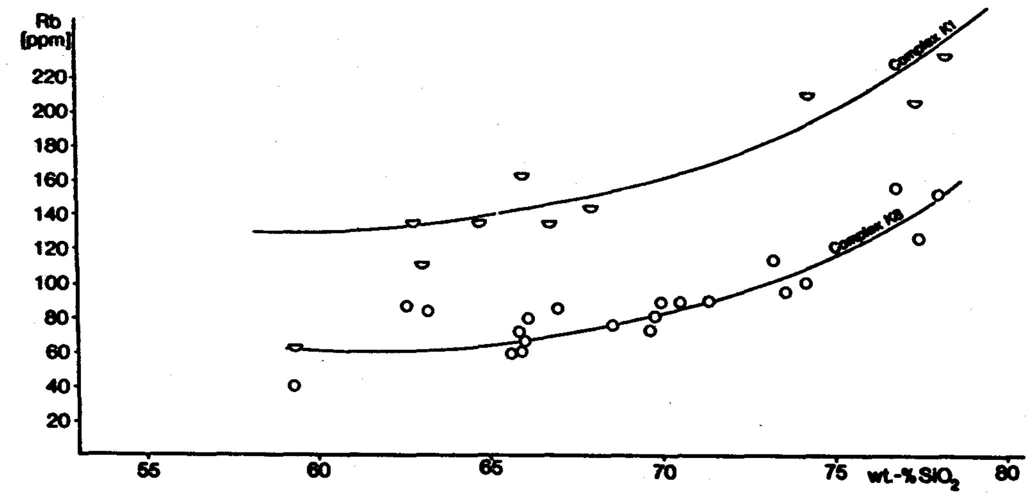

Fig. 5b. Rb - SiO_2 diagram showing the individual chemical evolution of each of the complexes.

(HFS) trace elements. In general, the rocks are distinguished by relatively high LIL/HFS element ratios. SiO_2 variation diagrams cover a SiO_2-range from about 50 to 78 wt.-% (62.6 - 76.9 for granitoids, 48.7 - 68.6 for xenoliths, 77,6 - 78,8 for aplites, 73.6 for one pegmatitic rock) and a considerable scatter of the LIL element contents is to be observed ruling out any simple genetic relation between the various plutonic bodies. The data do not support a derivation of the plutons from a common parental magma differentiated to varying degrees by fractional crystallization. On the contrary, it appears that each complex is characterized by a specific trace element pattern which presumably reflects compositional heterogeneities within the source material. Additionally, processes of magma mixing might contribute to a certain extent to the observed dispersion in the trace element contents.

Trace element relationships caution against accepting any single model of crystal fractionation from a common parental magma. It will be shown that each complex has its own trace element characteristics determined by different partial melting conditions (Fig. 5a, b). A homogeneous source definitely has to be ruled out, and support is provided for crystal fractionation of plagioclase, hornblende and REE-containing accessory phases at different crustal levels.

THE GRANITIC COMPLEX OF PUERTO VALLARTA

Fig. 6 presents the classification of the granitoids south of Puerto Vallarta according to the system of O'Connor (1965). It is to be seen that these rocks range in composition from tonalitic over granodioritic to granitic. Tables 1 and 2 show the respective major and trace element contents.

A regional distribution pattern of these rocks is mapped in detail. The available analyses give an overview along a S - N cross-section and show that a complicated history can be expected, which has to be installed in correlation to a detailed time sequence. For this purpose the following determinations have been made.

Existing age determinations

Up to now only a few radiometric age determinations are available. Gastil, Krummenacher and Jensky II (1978), Jensky (1975), obtained a K/Ar age of 81 Ma for the tonalites around Puerto Vallarta. In the Punta Mita granitoid complex a variety of rocks are exposed that were dated by K-Ar method as 71 Ma and 13.5 Ma, respectively. For the southern part of the granitoid complex of Puerto Vallarta K/Ar biotite-ages of 68 and 67 Ma were obtained (Barra de Navidad).

Besides several authors *e. g.* López Ramos (1979), De Cserna (1965), Campa and Coney (1983), Campa, Ramírez, Flores and Coney (1981), Grajales and López Infanzón (1983), Salinas (1984), Vidal Serratos (1982), Pantoja Alor (1982), Urrutia-Fucugauchi (1983) and González Partida and Torres Rodríguez (1988) have established a first model of the evolution of the Sierra Madre del Sur in the area between Puerto Vallarta and Acapulco. For the granitoid complex of Puerto Vallarta they assume a Jurassic age of intrusion and a reheating process starting at 108 Ma b.p. (González Partida and Torres Rodríguez, 1988). This interpretation is essentially based on deltaic and terrigenous continental sediments ("Lechos rojos") which surround and overlay the whole granitoid complex and are considered to be Jurassic in age. For all other granitoid complexes, even for the Punta Mita complex, Upper Cretaceous to Lower Tertiary intrusion ages are presumed.

Geochronological investigations

The aim of this investigation was to determine the intrusion- and cooling age of the granitoids of the complex of Puerto Vallarta (K 8) and to clarify the origin of the respective melts. In order to achieve this, Rb-Sr measurements of eight whole-rock samples (seven granitoids, one xenolith), of three mineral concentrates (two

Table 1

Major oxides of the investigated rocks and their CIPW-norms, Puerto Vallarta complex

	A89–1	A77	A79	A82–1	A81	A80	A88	A87	A72–1	A71
SiO_2	62.60	63.20	65.60	65.80	65.90	66.00	66.10	67.00	69.60	69.80
TiO_2	0.73	0.77	0.67	0.60	0.55	0.56	0.58	0.52	0.44	0.40
Al_2O_3	17.20	17.10	16.70	16.60	16.80	17.10	16.40	16.20	15.30	15.20
Fe_2O_3	1.28	2.00	1.85	1.93	1.82	1.72	1.07	1.11	1.37	1.49
FeO	4.10	3.15	2.64	2.27	1.83	2.02	3.21	2.88	1.71	1.25
MnO	0.10	0.12	0.10	0.07	0.07	0.07	0.07	0.08	0.07	0.07
MgO	1.50	1.57	1.37	1.77	1.52	1.47	1.19	1.06	1.18	0.96
CaO	4.64	4.33	3.95	4.53	4.32	4.39	4.00	3.73	3.19	2.81
Na_2O	4.17	4.80	4.58	4.33	4.52	4.57	4.06	4.15	4.22	4.23
K_2O	2.51	2.27	2.44	1.41	1.98	1.86	2.31	2.46	2.59	2.92
P_2O_5	0.22	0.24	0.21	0.18	0.16	0.17	0.18	0.16	0.12	0.11
H_2O	0.51	0.55	0.58	0.75	0.60	0.62	0.52	0.73	0.38	0.59
CO_2	0.05	0.08	0.09	0.06	0.08	0.05	0.04	0.05	0.07	0.04
Summe Σ	99.61	100.18	100.78	100.30	100.15	100.60	99.73	100.13	100.24	99.87

	A85–1	A75	A68	A74–1	A90–1	A91-1	A70	A73	A92	A65
SiO_2	70.00	70.60	71.30	71.40	71.60	72.00	73.20	74.20	74.20	74.60
TiO_2	0.42	0.34	0.39	0.37	0.22	0.29	0.24	0.18	0.17	0.20
Al_2O_3	15.20	15.20	14.40	15.10	13.90	14.70	14.00	13.80	14.10	13.30
Fe_2O_3	0.91	1.03	0.98	1.22	0.73	0.87	0.71	0.57	0.47	1.67
FeO	2.29	1.43	1.13	1.34	1.08	1.43	0.90	0.86	1.20	0.62
MnO	0.07	0.06	0.04	0.08	0.04	0.05	0.05	0.06	0.05	0.08
MgO	0.77	0.89	0.87	0.82	0.47	0.66	0.54	0.46	0.43	0.25
CaO	2.57	2.77	1.82	2.50	1.71	2.29	1.88	1.61	1.34	0.49
Na_2O	4.21	3.99	3.74	4.68	3.51	3.84	4.13	3.86	3.74	4.89
K_2O	3.16	3.13	4.64	2.54	4.17	3.51	3.30	3.85	4.14	3.70
P_2O_5	0.11	0.11	0.08	0.11	0.12	0.11	0.07	0.07	0.11	0.02
H_2O	0.36	0.61	0.48	nb	0.80	0.96	0.21	0.36	0.53	0.44
CO_2	0.04	0.06	0.07	0.05	0.05	0.05	0.04	0.06	0.06	0.06
Summe Σ	100.11	100.22	99.94	100.21	98.40	100.76	99.27	99.94	100.54	100.32

	A83	A93
SiO_2	74.60	76.90
TiO_2	0.14	0.05
Al_2O_3	13.40	12.70
Fe_2O_3	0.52	0.49
FeO	0.81	0.52
MnO	0.06	0.04
MgO	0.28	0.14
CaO	1.04	0.60
Na_2O	3.90	3.95
K_2O	4.49	4.35
P_2O_5	0.03	0.01
H_2O	0.36	0.40
CO_2	0.09	0.05
Summe Σ	99.72	100.20

(Table 1 - Cont.)

	A89–2X	A74–2X	A82–2X	A90–2X	A91–2X	A85–2X	A72–2X	A86L	A82–3G	A66–2G
SiO_2	49.80	53.20	55.90	58.10	60.20	60.70	65.50	48.70	59.30	68.60
TiO_2	1.33	1.10	0.93	0.91	0.91	0.74	0.65	1.18	1.44	1.32
Al_2O_3	20.00	19.60	18.50	17.30	17.40	17.00	16.10	16.60	13.30	12.00
Fe_2O_3	2.53	3.22	2.83	2.05	2.39	1.64	2.13	1.69	4.90	6.14
FeO	7.53	5.81	4.36	4.01	3.09	4.70	2.83	7.34	5.13	0.47
MnO	0.18	0.29	0.12	0.10	0.07	0.20	0.12	0.17	0.21	0.05
MgO	3.19	3.35	3.88	4.59	3.24	2.07	1.89	9.15	4.16	1.72
CaO	7.21	4.28	6.95	6.77	6.25	5.57	3.92	11.60	5.18	2.29
Na_2O	4.35	5.65	4.45	3.80	4.12	5.06	4.59	2.10	3.36	2.96
K_2O	2.29	2.70	1.25	1.57	1.41	1.81	1.56	0.11	1.87	3.47
P_2O_5	0.52	0.40	0.20	0.24	0.27	0.30	0.16	0.16	0.34	0.40
H_2O	nb	nb	0.80	nb	0.49	0.49	0.71	1.37	1.04	2.09
CO_2	0.09	0.06	0.06	0.09	0.05	0.06	0.09	0.06	0.09	0.06
Summe Σ	99.02	99.66	100.23	99.53	99.89	100.34	100.25	100.23	100.32	101.57

	A78P	A76A	A69A	A84A
SiO_2	73.60	77.60	78.10	78.80
TiO_2	0.07	0.11	0.14	0.05
Al_2O_3	12.80	12.30	12.20	12.90
Fe_2O_3	0.39	0.20	0.70	0.12
FeO	0.18	0.34	0.16	0.11
MnO	0.01	0.01	0.01	0.01
MgO	0.12	0.14	0.15	0.13
CaO	1.04	0.54	0.27	1.22
Na_2O	3.29	3.59	3.55	5.78
K_2O	5.17	4.56	4.81	0.60
P_2O_5	0.01	0.02	0.01	0.02
H_2O	0.23	0.33	0.16	0.37
CO_2	0.06	0.05	0.05	0.04
Summe Σ	96.97	99.79	100.31	100.15

biotites, one hornblende) and of five thin slabs across a contact granitoid/dioritic xenolith were carried out.

The samples were collected along the street from Puerto Vallarta to Manzanillo (for sampling localities see Fig. 2), because only along this road fresh rocks for determination could be collected. The composition of the samples ranges from tonalitic over granodioritic to granitic (Fig. 6). The results of the Rb-Sr - and K-Ar - analyses are listed in Table 3. The measurements were carried out on a Finnigan Mat 261 mass spectrometer. Analytical details and the constants used are given in Table 3.

Table 2

Trace element abundances of the granitoids of the Puerto Vallarta complex

	A89–1	A77	A79	A82–1	A81	A80	A88	A87	A72–1	A71
Li	14	15	5	16	21	17	16	16	24	23
Cr	10	10	9	16	10	12	10	9	13	8
Co	7	9	7	11	8	10	7	5	5	8
Ni	3	5	4	8	7	6	2	2	6	4
Cu	5	6	29	10	18	15	3	3	5	4
Zn	86	95	80	68	66	70	72	70	52	45
Ga	19	20	20	19	19	19	19	19	17	17
Rb	87	82	61	28	38	33	81	86	74	81
Sr	365	436	416	597	584	598	344	322	373	338
Y	29	31	27	6	8	10	23	24	15	14
Zr	250	314	277	98	96	102	232	197	128	125
Nb	8	9	9	6	7	7	9	8	9	9
Ba	850	950	1100	620	810	790	1050	1040	630	710
Be	2	2	2	1	2	1	2	2	2	2
Cs	nb	nb	nb	nb	nb	nb	nb	nb	nb	nb
V	61	61	61	81	66	61	55	47	47	41
Rb/Sr	0.24	0.19	0.15	0.05	0.07	0.06	0.24	0.27	0.20	0.24

	A85–1	A75	A68	A74–1	A90–1	A91–1	A70	A73	A92	A65
Li	16	25	28	nb	19	25	17	26	19	1
Cr	6	8	18	6	6	7	5	6	6	4
Co	2	5	3	4	3	2	1	2	3	3
Ni	3	4	10	3	2	3	4	5	3	2
Cu	6	4	6	2	nb	1	5	1	nb	3
Zn	67	48	21	55	34	46	40	31	29	80
Ga	17	17	16	18	16	17	16	16	17	17
Rb	86	66	157	66	138	129	85	102	167	61
Sr	278	406	277	279	211	258	283	228	131	64
Y	18	12	14	28	20	16	11	13	26	43
Zr	223	121	190	179	114	131	114	90	100	304
Nb	9	7	9	7	8	7	8	10	8	8
Ba	1590	1010	830	nb	1070	960	1320	1030	620	790
Be	2	2	2	nb	2	2	2	2	3	2
Cs	nb	nb	nb	nb	nb	nb	nb	nb	nb	nb
V	34	37	31	28	14	22	21	15	9	1
Rb/Sr	0.31	0.16	0.57	0.24	0.65	0.50	0.30	0.45	1.26	0.95

	A83	A93
Li	21	54
Cr	5	5
Co	4	2
Ni	4	3
Cu	nb	2
Zn	23	30
Ga	16	17
Rb	177	195
Sr	97	36
Y	33	45
Zr	103	89
Nb	9	10
Ba	660	400
Be	4	4
Cs	nb	nb
V	6	3
Rb/Sr	1.83	5.76

(Tab. 2 - Cont.)

	A89–2X	A74–2X	A82–2X	A90–2X	A91–2X	A85–2X	A72–2X	A86L	A82–3G	A66–2G
Li	14	nb	9	20	21	11	32	nb	nb	nb
Cr	13	13	31	152	77	7	12	443	39	34
Co	19	13	26	22	17	9	11	44	27	16
Ni	13	6	29	55	33	4	9	69	20	29
Cu	2	57	97	5	3	6	35	22	11	69
Zn	172	195	95	91	75	109	91	90	184	80
Ga	nb	27	22	22	nb	21	20	nb	nb	nb
Rb	89	146	21	62	54	45	75	2	39	76
Sr	429	310	671	730	876	336	368	188	359	429
Y	nb	32	16	12	nb	59	9	nb	nb	nb
Zr	nb	255	63	107	nb	174	122	nb	nb	nb
Nb	nb	11	7	6	nb	8	10	nb	nb	nb
Ba	1000	nb	610	710	720	610	710	nb	nb	nb
Be	2	nb	1	1	1	2	2	nb	nb	nb
Cs	nb	nb	nb	nb	nb	nb	nb	nb	nb	nb
V	154	nb	172	144	124	70	84	241	202	124
Rb/Sr	0.20	0.47	0.03	0.09	0.06	0.14	0.20	0.01	0.11	0.17

	A78P
Li	3
Cr	4
Co	2
Ni	1
Cu	1
Zn	8
Ga	14
Rb	65
Sr	137
Y	7
Zr	42
Nb	6
Ba	870
Be	1
Cs	nb
V	8
Rb/Sr	0.48

	A76A	A69A	A84A
Li	2	nb	nb
Cr	4	9	5
Co	1	nb	nb
Ni	2	4	nb
Cu	5	9	1
Zn	10	3	nb
Ga	15	nb	nb
Rb	127	91	11
Sr	63	37	180
Y	32	nb	nb
Zr	119	nb	nb
Nb	8	nb	nb
Ba	800	nb	nb
Be	2	nb	nb
Cs	nb	nb	nb
V	1	8	1
Rb/Sr	2.02	5.06	0.06

In Fig. 7 the results of the whole-rock isotopic Rb- and Sr- measurements (Table 3) are plotted in an isochron diagram. The data points scatter around a regression line. The conditions for an isochron *sensu stricto* are not satisfied. The slope of the regression line (MSWD 3.6) corresponds to an age of 88 ± 2 Ma. This age value is strongly influenced by the result of sample 93, which has a rather high 87Rb/86Sr ratio. This sample was taken from the outermost northern part of the pluton and is possibly affected by a post-intrusive (volcanic) event.

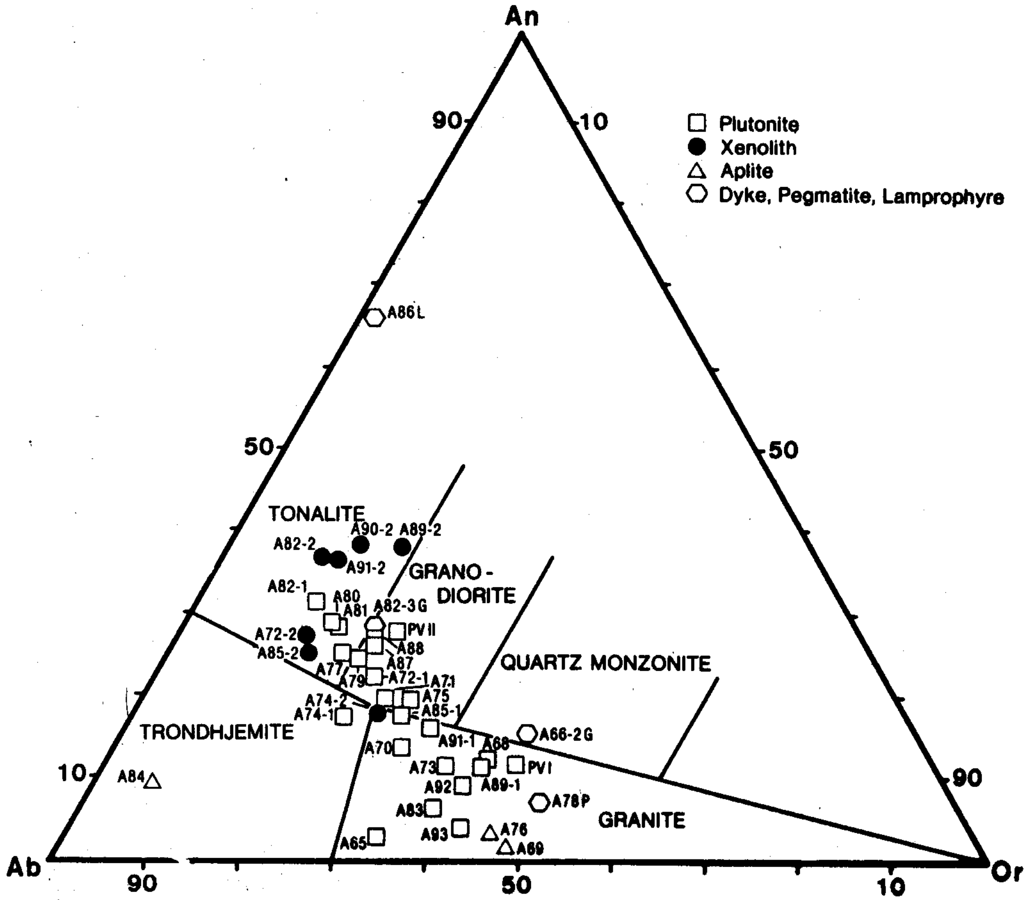

Fig. 6. Classification of the rocks of the Puerto Vallarta complex in the Ab - Or - An diagram.

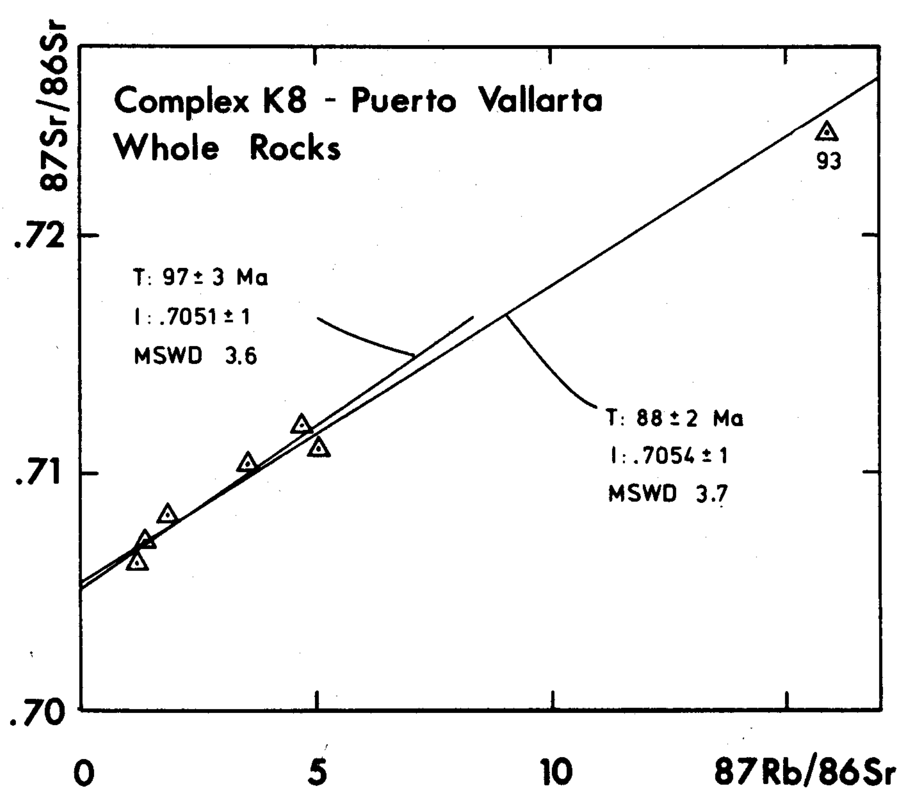

Fig. 7. Rb/Sr isochron diagram for seven whole-rock determinations of the granitoid of Puerto Vallarta (complex K 8). Calculation of the regression line according to Wendt *in* Brooks *et al.* (1968); error: 1-sigma, lambda 87Rb = 1.42 x 10EXP-11/a.

The calculation of the regression line through the remaining six points (MSWD 3.7) yields an age of 97 ± 3 Ma (Fig. 7). This value we interpret as maximum age of intrusion, whereas the value of 88 ± 3 Ma can be regarded as minimum age of intrusion of the investigated granitoids of the complex of Puerto Vallarta. Table 3 gives the results of the mineral measurements. The following age values were calculated:

- The biotite - whole-rock ages are 82 ± 3 Ma and 83 ± 3 Ma. These values represent cooling ages and give the time when the blocking temperature of the Rb-Sr system of the biotites was reached. This value is assumed to be 320°C ± 40 (Jäger and Hunziker, 1979).
- The K-Ar hornblende age is 86 ± 2 Ma. This age is also regarded as a cooling age. The blocking temperature in this case is about 530°C ± 40 (Harrison and McDougall, 1980).

Table 3

Results of Rb - Sr measurements of whole-rock samples and mineral separates from the Puerto Vallarta complex (K 8)

Sample	Rb (ppm)	Sr (ppm)	87Rb/86Sr	87Sr/86Sr	1-sigma
Whole-rock data					
PV–I	174	107	4.72	.71195	.00018
PV–II	82	199	1.20	.70624	.00005
A 83	177	102	5.04	.71098	.00010
A 90–1	144	225	1.85	.70822	.00015
A 91–1	126	269	1.36	.70714	.00033
A 92	169	138	3.55	.71036	.00010
A 93	196	36	15.9	.72426	.00011
Xenolith					
A 85–2	44	340	.37	.70520	.00011
Xenolith/Granite, Thinslab (see Fig. 10)					
Xen. A	112	379	.85	.70626	.00012
Xen. B	104	395	.76	.70621	.00010
Xen. C	92	331	.81	.70638	.00015
Gran. A	61	411	.43	.70613	.00010
Gran. B	43	389	.32	.70625	.00011
Biotites					
PV–I	1035	2	1652	2.631	.00706
PV–II	398	2	548	1.349	.00500

Potassium - Argon Dating of the PV–II Hornblende

40Ar(rad) (10EXP-6 ccSTP/g)	40Ar(atm) (%)	K (%)	t (Ma)
2.404 ±.024	10.4	.704 ±.0007	85.8 ±1.7

Carried out with a Finnigan MAT 261 mass spectrometer. Used constants: 88Sr/87Sr = 8.375. 85Rb/87Rb = 2.593. 1-sigma error of the 87Rb/86Sr ratio = ± 2 %. Sample localities are shown in Fig. 2.

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The radiometric data obtained for the intrusion and cooling of the granitoids of the complex of Puerto Vallarta are in good agreement with age determinations carried out by Silver *et al.* (1979) on rocks from the adjacent regions of the peninsula of Baja California and the states of Sonora, Sinaloa and Jalisco. During the typing of this paper, Zimmermann *et al.* (1987) report some K-Ar whole-rock - and biotite ages of the granitoids of the Puerto Vallarta - Río Santiago batholith. These values range from 55 Ma to 85 Ma.

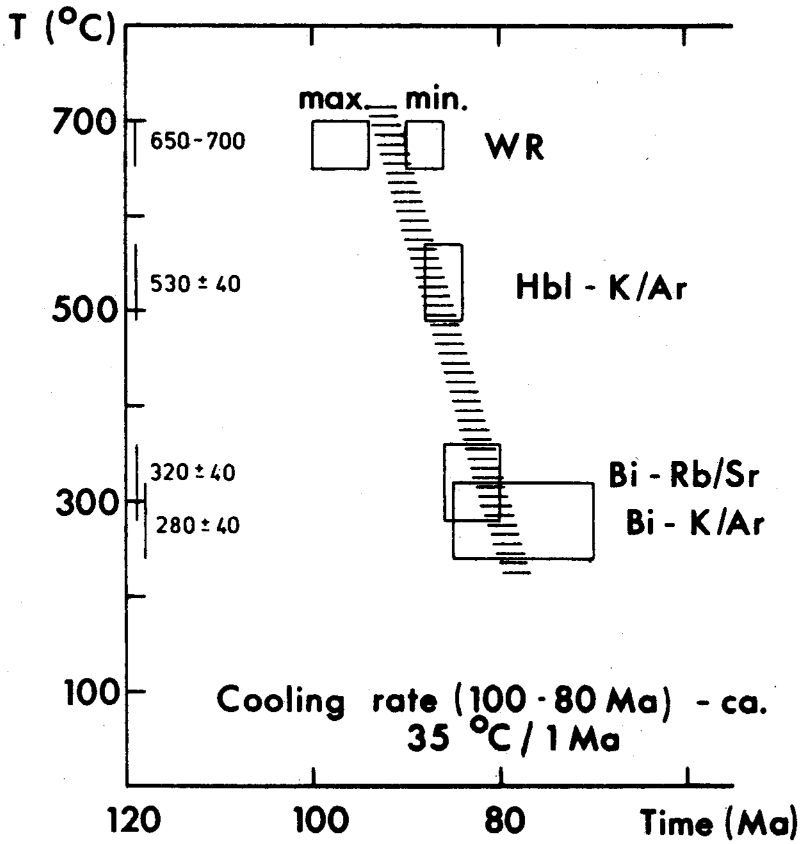

Fig. 8. Time/Temperature diagram of whole rock and mineral ages for the batholith of Puerto Vallarta. Also given are the used blocking temperatures (Jäger and Hunziker, 1979, Harrison and McDougall, 1980). Details, see text.

In Fig. 8 all age values of this study are listed in a time/temperature diagram:

- The maximum and minimum age of intrusion, 97 Ma and 88 Ma respectively, represent a solidus temperature of the pluton of 650 to 700°C.
- The hornblende cooling age of 86 ± 2 Ma at a proposed blocking temperature of 530°C ± 40 and
- the cooling ages of the biotites, 83 ± Ma, at a blocking temperature of 320°C ± 40.

K-Ar biotite ages cited in Gastil (1983) are also given. These values range from 85 Ma to 70 Ma, the blocking temperature is 280°C ± 40 (Jäger and Hunziker, 1979).

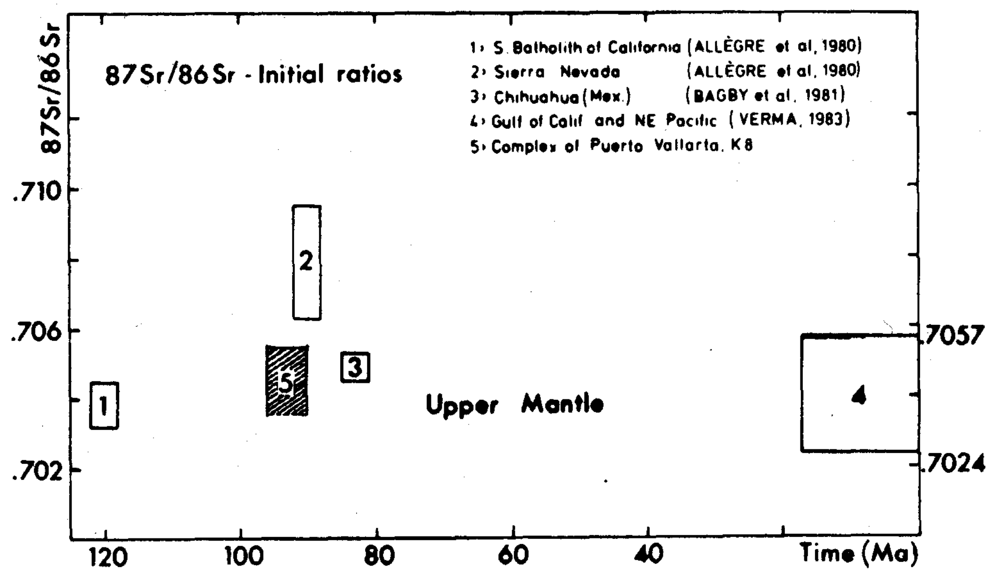

Fig. 9. Diagram time/87Sr/86Sr-initial ratios to demonstrate the evolution of Mexican and North American rocks. The black horizontal label gives the 87Sr/86Sr initial ratios of the Upper Mantle (0.702 - 0.706).

These data allow to reconstruct the temperature decrease with time and to estimate the cooling rate in the time interval between about 100 Ma to 80 Ma. Using the above mentioned values a T-decrease of 35°C/Ma is obtained. This value is significantly higher than the cooling rate from the northern part of the Gulf of California depression. Using biotite and zircon ages (Gastil, 1983), a cooling rate of only 12 - 17°C/Ma can be calculated.

The 87Sr/86Sr-initial ratios of the granitoids of the complex of Puerto Vallarta, as defined by the regression line, are 0.7051 ± 0.0001 to 0.7054 ± 0.0001. The scatter of the values, however, proves a significant variation of the initial ratios of the individual samples. The calculation of the initials of the single rock samples at the assumed time of intrusion yields values ranging from 0.7040 to 0.7060.

Comparable initial ratios at similar intrusion ages are known from other granitic plutons from Mexico (Chihuahua, Bagby *et al.*, 1981) and Southern California (Allegre and Ben Othman, 1980). Their initial ratios vary between 0.7032 and 0.7045 and 0.7045 and 0.7053 respectively (Fig. 9).

All 87Sr/86Sr values obtained are typical for rocks derived from the Upper Mantle. For instance, Verma (1983) presents 87Sr/86Sr values of young basaltic rocks from the northeast Pacific and the Gulf of California, which range from 0.7024 to 0.7057 (Fig. 9). White *et al.* (1987) report for the East Pacific rise area in front of Puerto Vallarta 87Sr/86Sr ratios from 0.70242 to 0.70252. Consequently, it seems possible that subducted oceanic crust, which was partially enriched in radiogenic 87Sr by alteration processes, is the source material of the granitoids of Puerto Vallarta. On the other hand, the variation of the initial ratios of the granitoids can also be explained by crustal contamination of a rising, initially homogeneous mantle melt. At present, it cannot be decided which of the two models might apply.

The results of the thin slab measurements (Table 3) are plotted in Fig. 10. As shown in the graph, the five slabs are taken across the contact dioritic xenolith/granite. From the isochron diagram it can be seen that the data points fit on a horizontal line. Obviously, the initial ratios of the xenolith and the surrounding granitoid rocks were different at the time of intrusion.

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This can be demonstrated more precisely in a profile diagram 87Sr/86Sr vs. number of slabs. The calculation of the 87Sr/86Sr ratios of the individual slabs for different ages shows that:

- the xenolith has a significantly lower initial ratio than the surrounding granite (0.7051 and 0.7058, respectively), indicating that both rock types are derived from different sources, they are not co-magmatic.

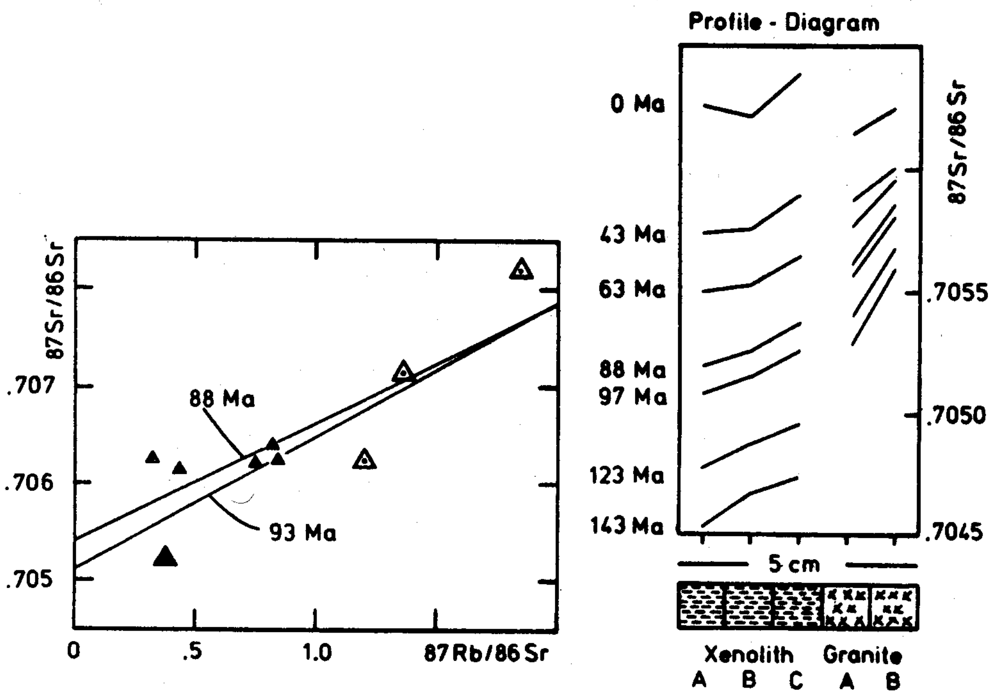

Fig. 10. left: Rb/Sr isochron diagram for the xenoliths (black triangles) and granitoids (triangles with point) of the Puerto Vallarta complex with two regression lines for 93 and 88 Ma. Large symbols: whole rock; small symbols: thin slabs.

right: Diagram to illustrate the changing 87Sr/86Sr ratios within the small areas of contact between dioritic xenoliths and granites calculated for different times. Details, see text.

- There had been a partial exchange of Sr-isotopes at the time of intrusion. This fact might be a further explanation for the varying initial ratios of the granitoids, as discussed before.

SUMMARY

1. The intrusion age of the granitoids of Puerto Vallarta is limited between 88 ± 2 Ma and 97 ± 3 Ma.

2. Mineral cooling ages are 83 ± 3 Ma for biotite (Rb-Sr) and 86 ± 2 Ma for hornblende (K-Ar).

3. The cooling rate of the complex in the interval from about 100 Ma to 80 Ma is approximately 35°C per 1 Ma.

4. The granitoids either originate from mantle-derived melts, that were contaminated by crustal Sr (enriched in 87Sr) or represent crystallization products of evolved melts that were generated from subducted oceanic basaltic crustal material.

5. The observed scatter in the initial 87Sr/86Sr ratios may be partly due to assimilation processes.

6. The granitoids and their xenoliths derived from different sources.

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