RESUME DE LA THESE

RELATIONS VOLCANOLOGIE-MAGMATOLOGIE-GEODYNAMIQUE : APPLICATION AU PASSAGE ENTRE VOLCANISMES ALCALIN ET ANDESITIQUE DANS LE SUD MEXICAIN

(Axe Trans-mexicain et Province Alcaline Orientale)

Soutenue le 12 Juin 1981, à l'Université Clermont II
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Relations volcanology-Magmatology-Geodynamic : The transition between andesitic and alkaline volcanisms in southern Mexico

(Trans-Mexican Volcanic Belt and Eastern Alkaline Province).

This thesis is subdivided into six parts :

1 - The definition and the geological survey of the volcanic provinces which outcrop in south-eastern Mexico : The N-S directed Alkaline Province, widespreading along the eastern Mexican coastal plain, and the eastern part of the Mexican Volcanic Belt. On the basis of their age and their spatial relations, these provinces remain difficult to reconcile with the classical concept of a Circum-Pacific volcanic zone.

2 - The volcanological study of major andesite composite volcanoes in this zone. It was necessary to define the magmatic evolution during the last 2 Ma. The study leads to propose a volcanological model valid for this type of continental andesitic volcano-complexes.

3 - 4 : In parts 3 and 4 the petrological characteristics and the evolution (both in time and space) of each province are presented. 500 new analyses (major and minor elements) and mineralogical data support this study. In the major volcanoes such as Nevado de Toluca, Pico de Orizaba and Popocatepetl, the compositional characteristics of the lavas are correlated with the volcanological stages of development.

5 - According to trace-elements geochemistry (REE, Sr isotopes, LIL Elements) hypotheses on the genesis of primary magmas are discussed.

6 - The compilation of these data, in the light of geophysical results on the Pacific plate subduction in South Mexico leads to a new interpretation of the andesitic province and allows to propose a model which explains the transition between the two types of magmatism during the last 4 Ma.

DEFINITION OF THE MAGMATIC PROVINCES

Structural outlines :

South-eastern Mexico is characterized by north-south Miocene-Plio-quaternary distensive faults that separate the coastal plain from the Altiplano. These faults constitute the boundary between a region of normal continental

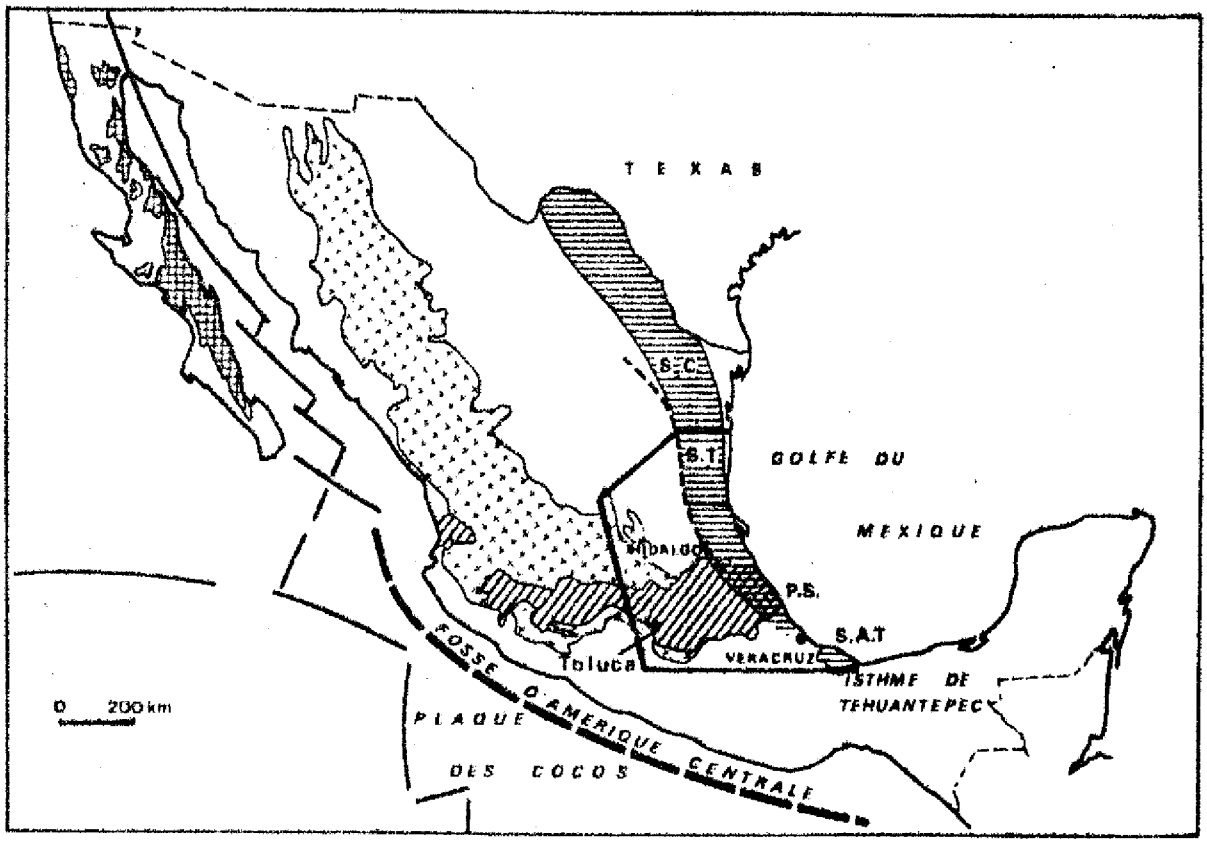

Fig. 1: Schéma de localisation des provinces volcaniques du Mexique montrant les limites de la zone d'étude. Les analyses chimiques nouvelles reportées dans ce mémoire (470 pour les majeurs) proviennent toutes de l'aire encadrée. La zone d'interférences entre la Province Alcaline Orientale (hachures horizontales) et l'Axe andésitique trans-mexicain constitue le centre du sujet et a été particulièrement étudiée dans les régions de l'Hidalgo (partie nord) et Veracruz-Toluca, volcans Pico de Orizaba-Popocatepetl-Nevado de Toluca (partie sud). Pour plus de détails, se reporter aux figures 2 (Province Alcaline) et 18 (zone orientale de l'Axe trans-mexicain).
Trame quadrillée : Province californienne - Croix : Province andésito-ignimbritique de la Sierra Madre Occidentale.
Principaux centres de la Province Alcaline Orientale : SC : Sierra de San Carlos ; ST : Sierra de Tamaulipas ; PS : Massif de Palma Sola ; SAT : Massif de San Andres Tuxtla.

crust and a thinned crust domain.

The alkaline province in Eastern Mexico :

Alkali lavas were found at the eastern termination of the calc-alkalic Trans-Mexican Belt (Palma Sola Massif and Sierra de Chiconquiaco). Here, the faults intersect perpendicularly the andesitic province just east of the Volcano Pico de Orizaba. Alkaline series also occur to the north, along the entire Gulf Coast and to the south (San Andres-Tuxtla massif). This province (1300 x 50-200 km) can be subdivided into two parts, the Gulf Coastal Plain series and the trap series, the latter along the faulted zone at the altiplano border. The Coastal Plain series include a variety of silica undersatured lavas : nephelinites, basanites, alkali-basalts, trachytes and phonolites, as well as alkaline to peralkaline rhyolites. The age of these series varies from oligocene to recent. Geological and petrological studies of Sierra de Tamaulipas (a ring structure, 40-50 km wide) and of the Palma Sola complex are included. Scattered volcanic edifices of alkali-basalts, trachybasalts, basanites and nephelinites in the Tampico region are also presented as well as a series from Tuxtla.

The traps on the border zone of the altiplano are made of alkali-basalts, hawaiites, mugearites, with some transitional basalts and even some lavas of tholeiitic composition. In the Sierra de Chiconquiaco, where the sequence is thick (> 800 m), the lower part of the series ($\simeq 4 - 3$ Ma) is alkaline in composition whereas the compositional characteristics of the upper volcanic association (< 3 Ma) is transitional to tholeiitic.

The Trans-Mexican Volcanic Belt (M.V.B.) :

The E-W directed M.V.B., is built upon a widely continuous Miocene andesitic belt that runs parallel with the Pacific coast from California to Guatemala. K-Ar data, petrological studies and field investigations lead to divide the Plio-quaternary province into two sections. The northern area consists of basalts and relatively undifferenciated lavas (plateau basalts), their petrological characters are intermediate between alkaline and calc-alkaline ; they have been emplaced mainly between 2.5 and 1.5 Ma ago. Some volcanic series which mark a southward extension of this volcanism are 1.5 - 1.7 Ma in age and include andesites and basalts with characteristics similar to those of the northern area.

The active M.V.B., forming the southern area, consists of 10 major central volcanoes or volcanic systems, and of several thousands simple monogenetic cones. These cones include basalt to acidic andesite compositions (over 60% SiO_2) but are generally of basaltic andesite composition (52-56% SiO_2). In the western section of the M.V.B, Sanganguey, Ceboruco, Tequila and Colima volcanoes are medium-sized, reaching 1000 to 2500 m above the basement. The Nevado de Toluca (4650 m) is located in the central area. In the east are the two largest volcanic systems : the Popocatepetl (5450 m) flanked by the eroded volcano Iztaccihuatl, and the Pico de Orizaba (5675 m) which forms the southern section of a north-south volcanic range about 80 km in the length. Just east of the Pico de Orizaba, the eastern alkaline province exhibits an east-west geochimical break charaterized by the occurence of alkaline lavas. The present M.V.B. terminates near the Pico de Orizaba, whereas Palma Sola and San Andres volcanoes belong to the alkaline Province. On the other hand, Volcan Chichon is related to an other subduction extending south of the Tehuantepec Ridge.

Large recent calderas, 10-15 km in diametre, with associated ignimbrites, occur in the northern part of the M.V.B., in the Guadalajara area and at the north-western side of the Pico de Orizaba - Cofre de Perote andesitic chain (Teziutlan-area). Field data, chemical analyses and a structural evolution of the Los Humeros-Teziutlan complex are presented.

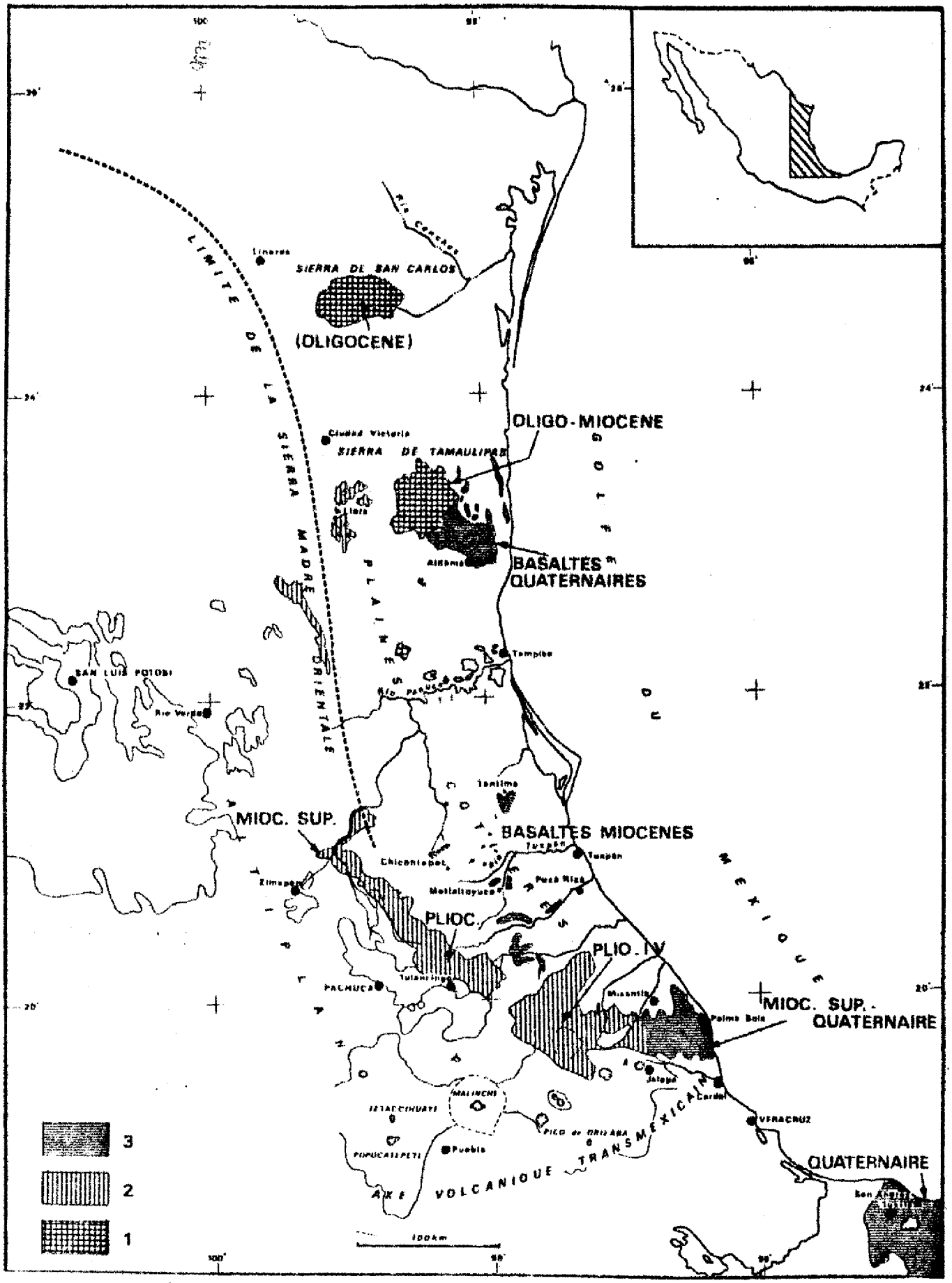

Fig. 2: La province alcaline orientale. 1 : séries sous-saturées et sursaturées des Sierras de San Carlos et Tamaulipas. 2 : sous-province de la zone des fractures (rebord des plateaux). 3 : formations basaltiques des

Relations between the andesitic and alkaline provinces in south-eastern Mexico :

Concerning the andesitic volcanism, the data indicate that the zone has been submitted to various periods of volcanic activity since the Early Miocene : the major activities seem to have occured about 20-15 Ma and 9-6 Ma. Ages of 3-0 Ma correspond to the M.V.B., the southern part more recent than the northern part. On the other hand, in the eastern alkaline Province, activity has moved southward from Tamaulipas to the Veracruz region. The alkaline traps, which occur in the fault zone of the Altiplano border, show a similar shift of the rifting, between 9 and 3 Ma ago, from northern Hidalgo to Veracruz.

The periods of alkaline magmatism were not contemporaneous with andesitic phases. The two types occur independently, the andesitic one having an east-west trend and the alkaline one a north-south migration. Such patterns induce a crossing and interference of the two Pliocene and Quaternary fields of magmatism. These provinces remain difficult to reconcile with the classical concept of a circum-Pacific volcanic zone. S.E. Mexico can be understood as a transition zone between areas affected by subduction of the Cocos plate, and areas affected by oblique extension as a result of north-south rifting in the eastern alkaline province and the intracontinental faults of the M.V.B. Simple models relating magmatism to a subduction zone are likely not valid.

VOLCANOLOGY

In order to follow the magmatic evolution within the neo-volcanic belt and the transition from alkaline to andesitic magmatism during the last 4 Ma, a volcanological study was undertaken. The alkaline "traps series" did not need more investigation whereas a detailed study of the four major andesitic volcanocomplexes of the area was necessary. These volcanoes are Nevado de Toluca, Popocatepetl, Malinche and Pico de Orizaba. According to their duration (more than 1 Ma.), the evolution of magmatic units and related primary magma composition appears representative of the magmatic evolution of the province at a place.

Nevado de Toluca and Malinche show a simple evolution. On the contrary Popocatepetl and Pico de Orizaba display a more complicated model : For example, the Pico de Orizaba is composed of a primitive strato-volcano raised by recent summit cone ; it has been built by three very distinct volcanologic and magmatic phases (phases 1-2 are valid for Nevado de Toluca and Malinche) :

1 - The first phase , probably discontinuous effusive activity, lasted more than 1 Ma. It is mainly composed of two-pyroxenes andesites with scarce associated basaltic and dacitic lava-flows. Amphibole can appear as an accessory mineral in most differenciated lavas. Numerous massive and auto-brecciated lava-flows pass outward into thick conglomeratic formations.

2 - The second phase is of short duration -about 100 000 years or less in comparison with the first stage. It began with the formation of a caldera (consecutive in Nevado and Malinche to the eruption of important ash and pumice pyroclastic flows). This caldera is followed by the extrusion of amphibole-dacite domes and the overflow of viscous acid (andesite to dacite) lava-flows. An intense explosive activity develops : pelean "nuées ardentes" are associated to the extension of the domes ; numerous plinian eruptions leading to wide-spread dacitic air-fall deposits (ash and pumice), are produced. This sequence of events is interpreted as the progressive emptying of a superficial chamber containing differenciated magma.

3 - The age of the recent phase of Pico de Orizaba is better defined. It started 13 000 years B.P. with the eruption of dacitic ash-flow containing pumice and scoria-bombs. This being such an intense event, erasing the top

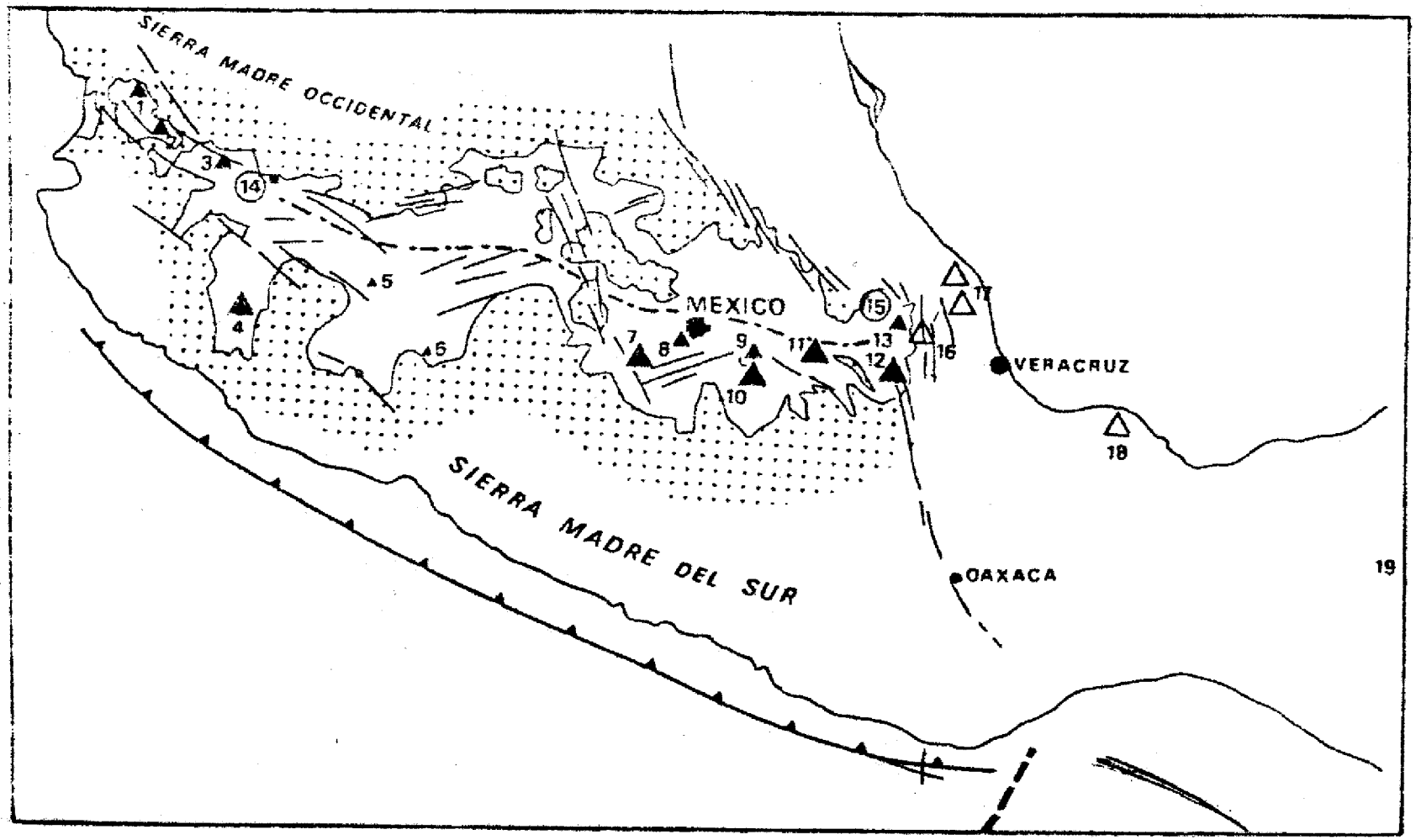

Fig. 3 : Esquisse volcano-tectonique simplifiée de la Province néo-volcanique trans-mexicaine. Les principaux accidents limitant les zones d'effondrements ont été reportés ainsi que les grands volcans. On remarquera que la province calco-alcaline est interrompue au niveau du Pico de Orizaba (12), le magmatisme de Palma Sola et de San Andrés (18) étant partie intégrante de la Province alcaline orientale (Robin, 1976). La ligne discontinue représente la limite approximative de l'extension des formations pliocène sup-quaternaire inf. (2,5-1,6 MA) de type Atotonilco et Pachuca, surtout développées dans la partie orientale au Nord et Nord-Ouest de Mexico.
1: Volcan Sangangüey 2: Ceboruco 3: Tequila 4: Colima 5: Paricutin 6: Jorullo 7: Nevado de Toluca 8: Ajusco 9: Iztaccihuatl 10: Popocatepetl 11: Malinche 12: Pico de Orizaba 13: Cofre de Perote. Calderas avec volcanisme rhyolitique 14: La Primavera et 15: Complexe de Los Humeros - Teziutlan. Volcanisme alcalin 16: Sierra de Chichinautzin 17: Massif de Palma Sola 18: Volcan San Martin (massif de San Andrés Tuxtla).

of the anterior volcano and building a large crater (4-5 km wide). The present-day cone, of 1,400 - 1,500 m elevation, grew in this crater. During a period of 7,000 to 8.000 years, the new strato-volcano experienced various important pyroclastic eruptions with a cycle in order of 1,000 to 1,500 years. The pyroclastic flows (ash, pumice and bombs) associated with air-fall deposits are of "St. Vincent type". They present an heterogeneous magma, dacitic and andesitic. The dacitic component is similar to previous differenciated materials. On the other hand, the andesitic magma appears somewhat similar to lava-flows from morphologically young cones erupted outside the central vent system. This eruptive cycle can be interpreted as the result ofvarious injections of deep basic magma within the crustal chamber. Since 5,000 years the activity of the modern Pico de Orizaba appears again essentially effusive (andesites) with periodic plinian eruptions.

After a complex evolution, a similar cycle of "nuées St Vincent" is described in Volcan Popocatepetl. A comparative model for these four volcanoes is given.

PETROLOGY : PROCESSES SUBSEQUENT TO GENERATION OF PRIMARY MAGMAS : FRACTIONAL CRYSTALLIZATION AND MAGMA MIXING

The alkaline magmatism :

Coastal plains : Miocene alkali-rhyolites and peralkaline rhyolites are associated with a transitional basalt series. They are almost aphyric and contain sanidine, quartz and acmitic pyroxenes. Feldspathoïd-bearing syenites, agpaïtic or miaskitic varieties are known ; they consist of sodic amphiboles, acmite, nepheline, aenigmatite, and alkali-feldspars. Upper Miocene oversaturated trachytes occur together with peralkaline rhyolites whereas recent (Pliocene-Quaternary) fayalite trachytes and phonolites are associated with alkali-basalts. Alkali-basalts-trachybasalts sequences are common in the Tampico Plain and in the Palma Sola Massif (Pliocene to Quaternary) ; they constitute the major part of the Quaternary Tuxtla volcanoes.

Traps : These lavas extend in the faulted zone, from northern Hidalgo (and Tamaulipas) to the crossing area between the two provinces. The lower units consist of basalts (ol + cpx) with plagioclase, Ti-augite and Ti-mt into the groudmass. During the differenciation process, the crystallization and parting of pl-phenocrysts is delayed. On the contrary, this mineral appears at liquidus with olivine in the upper transitional series. These sequences

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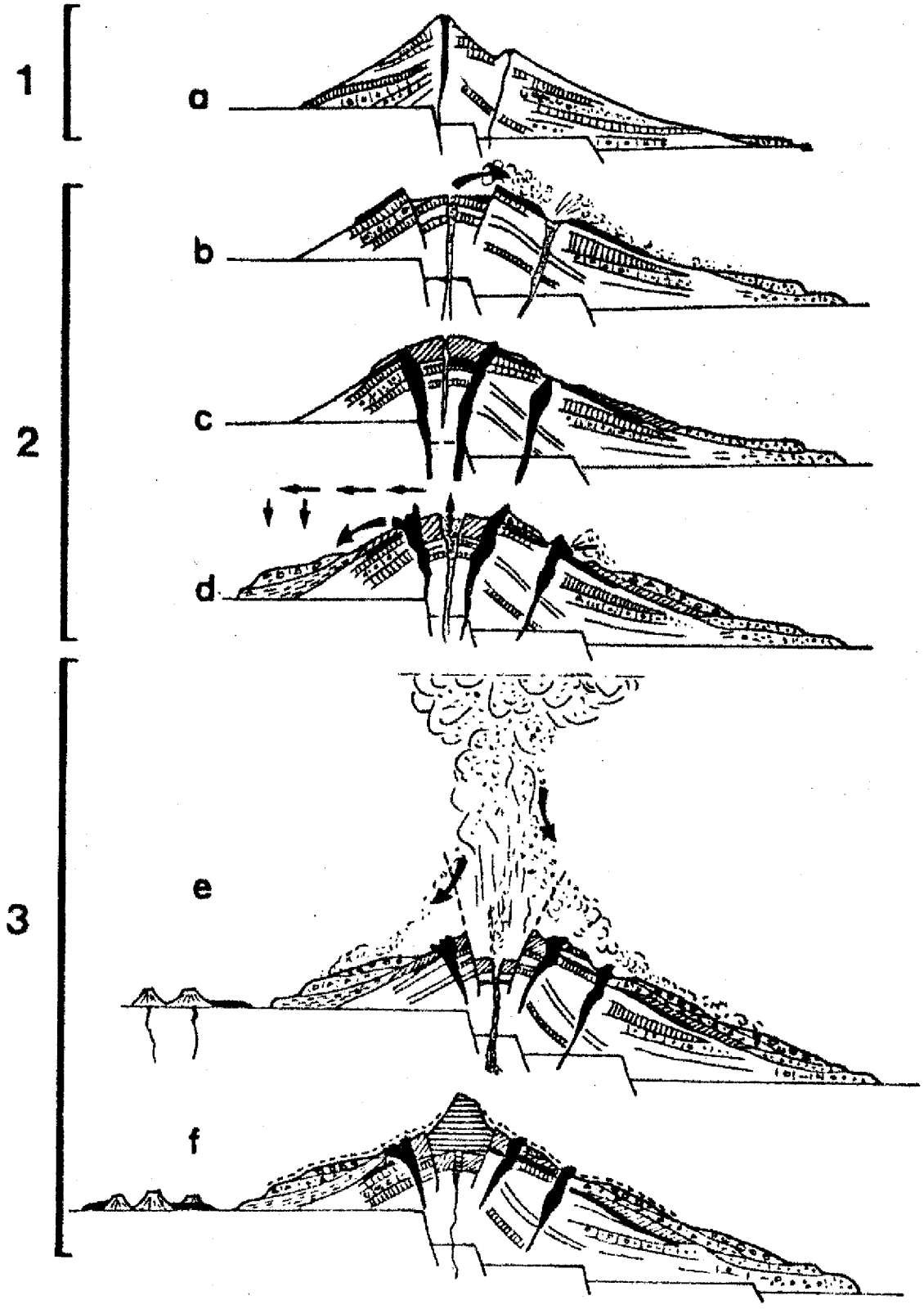
- Schéma montrant l'évolution du Pico de Orizaba.
1. Première Période (plusieurs centaines de milliers d'années) : a - Construction d'un volcan régulier lavique - coulées, coulées autobrechiées - conglomérats - Andésites à deux pyroxènes (+ amphibole peu représentée au sommet de la série).
2. Deuxième période (courte en comparaison de la première : de l'ordre de la centaine de milliers d'années) : b - Formation d'une caldera ; c - Montée de dômes dacitiques et remplissage de la caldera par des coulées visqueuses d'andésites à amphiboles. d - Activité dacitique explosive : nuées péléennes et éruptions pliniennes (retombées ponceuses) en alternance.
3. Période récente (15 000 ans) : e - Volcanisme basique sur le pourtour du volcan : cônes et coulées (Ciudad Serdan). - Dans le volcan central : émission des nuées retombantes St Vincent à magma hétérogène (basique et acide) et ouverture d'un grand cratère (ou petite caldera : 4-5 km de diamètre). f - Début de la construction du cône terminal après les premières éruptions St Vincent - l'activité redevient surtout lavique (coulées d'andésites) - projections épisodiques de cendres et ponces - Nouveaux cônes sur la périphérie.


1
a
2
b
c
d
3
e
f

present many basalts with high Mg/Mg + Fe ratios, low DI, High Ni, Cr, Co and low K, Rb concentrations, which are considered as very low differenciated lavas, close from primary magmas compositions.

The transition zone : northern part of the neo-volcanic Belt :

The Atotonilco Province (≃ 2,7 - 1,5 Ma) : Normative composition of most of the basalts show either a little quartz (< 3%) or hyp + ol, or ne (< 3%). The mineral paragenesis is ol - pl - cpx - FeTi oxydes. They contain high TiO_2 and relatively low values for basalts from an andesitic province. The chemical characteristics of the differenciated lavas range between alkaline and sub-alkaline domains ; both K - rich and Na - rich trachy-basaltic types are observed.

Active andesitic province (younger than 1,5 - 1,6 Ma) :

The early basalt-andesite-dacite suites of the major volcanoes : In the oriental M.V.B, the northern eroded (non-active) volcanoes as Cofre de Perote and the primitive volcanoes of the southern cordillera (phase 1 of the development of the major volcano-complexes) consist of basalts-basaltic-andesites-andesites (+ scarce dacites) suites. The chemical characteristics of the basalts are similar to those in the north. However, a ligh increase of K and Rb is noted. This indicates an inverse corelation with the distance from the trench. Early precipitation of the Fe - Ti oxydes with olivine causes a silica increase, sufficient to allow appearance of opx in the mesostasis of the intermediate lavas. The details of differenciation processes by fractional crystallization are given for each suite, using incompatible elements (Rb, Th) as differentiation index.

The andesitic suites : basaltic andesites (as primary magmas) - andesites - dacites - rhyodacites : In complexes such as Pico de Orizaba the end of the first phase is marked by new andesitic suites cogenetic with basaltic andesites. These later cannot be chemically correlated (by fractional crystallization or magma-mixing processes) with the preceding basalts. On the other hand, basalts are sometimes absent : specially for volcanoes which are not far from the trench : e.g. Nevado de Toluca and volcanoes of the western M.V.B. part. In Nevado de Toluca, the compositional range covers the interval 57-66 per cent SiO_2.

The recent series : summit cones of Pico de Orizaba and Popocatepetl, and recent monogenetic cones : basalts, andesitic-basalts (51-53 % SiO_2), basic andesites (53-56 % SiO_2) and more seldom andesites occur in the monogenetic cones. In the eastern area the Ni contents (55-185 ppm), Cr contents (85-285 ppm) and MgO/FeO ratios (≃ 1,25 with MgO up to 10%) as well as very low K, Rb or Ba concentrations, for basic andesites containing 54-56 % SiO_2, suggest that these lavas may be primary or relatively undifferenciated lavas. Their eruption was associated with local extension affecting the Valle de Mexico or Valle de Puebla.

In the summit cones of Pico de Orizaba and Popocatepetl, the activity is marked by eruptions of Saint-Vincent-type followed by a new basic effusive activity. All mineralogical and chemical data stress the part of magma-mixing processes in these recent phases. For Pico de Orizaba, the dacitic pole of the mixt-magma is similar to previous differenciated materials. The basic pole appears identical to lava-flows from the young cones erupted outside the central vent. For Popocatepetl, the difference in composition between the two components of the mixt-magma is less marked. These components resemble the final materials from two distinct differenciated suites of fractional crystallization.

A mineralogical study of olivine, clinopyroxene and plagioclase separates including calculation of D sol/liq for Ni, Mg, Cr, Co, Ba, Rb, Sr... allow an approach of thermodynamic conditions existing at various levels of fractional crystallization. The results suggest that each suite has known various stages of segregation into deep reservoirs (within the upper mantle or lower

continental crust) or superficial magmatic chambers. The data are summarized in schematic models showing the magmatic evolution of each major volcano or suite. The main conclusion which appears from the results is that an andesitic volcano as Popocatepetl or Pico de Orizaba is made of various magmatic suites of distinct origin, each of these suites following an own magmatic process based on fractional crystallization and/or magma-mixing.

In the light of field studies and of geochronological data (K-Ar, C14), a vertical magmatic zonation (with time) is often well marked, even on the level of a simple volcano. This explains the lack of a chemical zonation throught the andesitic province. The evolutions with time of K/Rb, Ba/Sr, and Rb/Sr ratios are defined and discussed.

CHEMICAL CARACTERS OF PRIMARY MAGMAS- PETROGENETIC HYPOTHESES

Alkaline magmatism :

The chemical characteristics of very low differentiated basalts from two traps units are considered. The first one, Ca 300m thick and of 7 Ma in age, is located in the north of Hidalgo state outside the Miocene andesitic province. The subduction has probably no effect on these alkaline and transitional lavas emplaced during a period of quiescence or slowing subduction. The second sequence, more than 800 m thick, corresponds to the Sierra de Chiconquiaco, located on the eastern side of the neovolcanic chain, upon the same fault-system which affected during recent times the Pico de Orizaba-Cofre de Perote complex. The age of the series varies from 4 Ma (alkaline) to Recent (transitional basalts and olivine tholeiites).

On the basis of LREE/HREE ratios, major and minor element concentrations, hypotheses on the origin of primary magmas are discussed. They agree with a stratified mantle model. In the Chiconquiaco series, the two major types represent separate parent magmas. The data indicate an origin by partial melting of garnet peridotite for the lower group (alkalic) whereas subalkalic upper lavas were the product of more voluminous melting in a spinel peridotite layer. This result can be interpreted as the ascent of the thermal regime or the progressive melting of a mantle diapir rising through the upper mantle between $\simeq$ 4 and 2 Ma ago.

Pliocene and lower quaternary suites (2.6 - 1.6 Ma) :

87 Sr/86Sr ratios, ranging between 0.7041 and 0.7044, high Ni, Cr contents and Mg/Fe ratios of basalts, REE and LIL Elements concentrations (Rb, Ba, U, Th) suggest an origin from low degrees of partial melting of garnet peridotites ; such hypothesis is consistent with LREE/HREE ratios. $D_{Ni}^{Ol\text{-}Liq}$, $D_{Fe\text{-}Mg}^{Ol\text{-}Liq}$ and $D_{Ni\text{-}Mg}^{Ol\text{-}Liq}$ suggest balance temperatures and pressures that indicate some differenciation at depth. The low K, Rb contents of these basalts in relation to the basalts of the M.V.B. and comparatively 87Sr/86Sr ratios tend to minimize any contribution from fluids released by subducted plate as suggested by various hypotheses.

Active andesitic province (younger than 2 Ma) :

Sr isotopes ratios are all consistent with an origin of magmas from the mantle and suggest that contribution from the continental crust is negligible, in contrast to andesites in margins with thick continental crust.

Basalts from the lower group : correlations between Rb, Sr, Ba, and K, as REE and LIL element concentrations are used to comment on various petrogenetic hypotheses. There is a good K-Rb correlation ; within near-primary magmas, deviations from this correlation correspond to lavas with low K/Rb ratios and with high Ba concentrations. Other basalts have high K/Rb with high Sr and low Ba (Sr $\gg$ Ba). The K/Rb, Ba/Sr and Rb/Sr ratios

cannot be accounted for either by contamination or by fractional crystallization processes. From the stability conditions of the minerals that control Rb, Sr, K and Ba in the mantle and from published Dsol/liq. estimated for basalts, the following origins are discussed :

1 - Basalts with low K/Rb and high Ba : low degrees of partial melting of amphibole-bearing peridotites in the upper mantle at less than 75 km, or at depths exceeding 75 km within stability field of phlogopite alone. For some basalts in the northern area, low La/Tb ratios indicate an origin by partial melting of amphibole - or spinel peridotite.

2 - Basalts with "normal" K/Rb, Sr, and Ba : most of the basalts at the origin of the suites forming the "primitive" stratovolcanoes (age $\simeq$ 1 to 1.5 Ma) : Variable degrees of melting of spinel or garnet peridotites, with no influence of the subducted oceanic plate other than fluid supply causing the melting.

3 - Basalts, basic andesites and andesites from the recent phase : Basalts, basic andesites and andesites of the recent association have high K/Rb, high Sr, and low Ba (high Ni, Cr, Co, and Mg/Fe ratios in relation to SiO2 , the hight K/Rb ratios result from the very low Rb values, but K is also low and these lavas have much in common with series of islands arcs. As Rb and Ba do not increase in the same way as Sr, contamination by continental crust may be excluded and this is consistent with the 87Sr/86Sr evidence. It seems that micas and clinopyroxenes are the only minerals that control high Sr and very low Ba/Sr during melting of the mantle or subducted oceanic lithosphere. SiO2 contents are also compatible with the hypothesis of reaction (and fractional crystallization) of andesic or dacitic fluids from the oceanic plate within the mantle. Partial melting of new bodies of "enriched mantle" (pyroxene and garnet rich bodies) would produce these andesitic "primary" magmas marked by an increase in La/Tb and low Ba/Sr.

CONCLUSIONS

The characteristics of the volcanic suites in southern Mexico demonstrate the varied influence of subduction over the magma composition. The subduction has no effect on alkaline and transitional lavas outcroping along the plateau. It has very small effects on Plio-Quaternary suites in the north of the province, and a few effects (supply of volatils, H20) on most of the calc-alkaline volcanic series of the M.V.B. In the eastern province, only a small amount of the primary magmas seems to have been affected by fluids from the oceanic plate.

For this region, this fact leads to subdivide the gradual transition from alkaline to calc-alkaline series into various periods :

1 - A first event without relation with the subduction : alkaline series from Miocene to lower Quaternary along the altiplano border. Upper Quaternary sequences occur also in the Coast Plains.

2 - The emplacement of the andesitic province , in the northern M.V.B., between 2,6 (3) and 1,6 (2) Ma : an imperfectly andesitic province, without major strato-volcanoes developed by differenciation of basaltic magmas : poorly differenciated plateaux series, intermediate between alkaline and calc-alkaline. More recently in the south, a few series include andesites and scarce dacites.

3 - The development of the andesitic province in the southern area, mainly between 2 (1,6) and $\simeq$ 1 Ma ago : it is characterized by basalts as primary magmas originated under "wet" conditions within the mantle (release of H20 from the subducted plate). This stage corresponds to the primitive volcanoes of the actual M.V.B. In the western part (west of Nevado de Toluca), basic andesites can appear as primary magmas during this period.

4 - The maturity of the province (less than 1 Ma) : characterized by

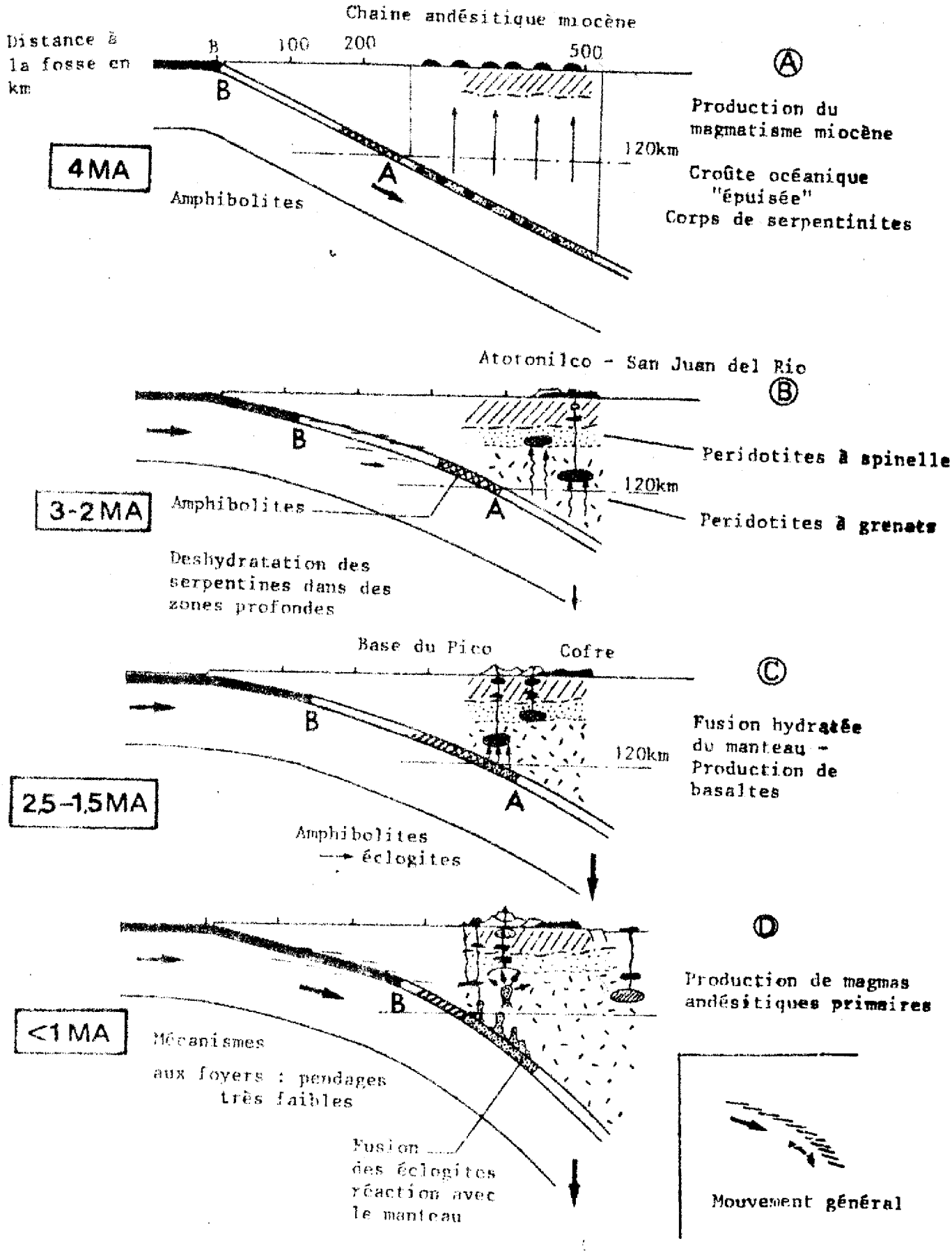


Fig. 4: Essai de corrélation entre la subduction de la plaque des Cocos, la répartition et la nature du volcanisme plioquaternaire. Les étapes A, B, C, D sont décrites dans le texte.

a variety of primary magmas : basaltic and andesitic ; the andesitic magmas are more abundant and early generated in the western volcanoes than in the eastern M.V.B. (Pico de Orizaba and Popocatepetl). In the same time, the part of the fluids expelled by the subduction may increase towards the west, where the M.V.B is nearer to the trench ; this may account for the abundance of monogenetic cones with "primary" or little differentiated lavas in the west.

These results are correlated with geophysical data recently obtained in the area. These data indicate a new arrangement within the subduction of Cocos Plate about 4-5 Ma ago : the subduction was then affected by a rotation (pivoting subduction). Problems such as (i) the migration of volcanism from the north to the trench, (ii) the contemporaneous emplacement of the magmatism all along the province, (iii) the poorly developed province to the north, during only 1 Ma... do not agree with a new system of subduction where the volcanism is produced when the slab reaches a sufficient depth within the mantle. On the other hand, if we consider a subduction rate of $\simeq$ 7 cm/year, since 4-5 Ma the slab is not able to reach the volcanic zone. A model including the Miocene slab of anterior subduction is proposed. This model takes account of the different particularities previously discussed and explains the successive types of primary magmas at each point of the andesitic chain. In a synthetic chapter on volcanological data, it is stressed that such petrological evolution (complicated by magma-mixing phenomenous) can be applied for the development of major volcano-complexes.