Atti Accademia Nazionale dei Lincei

Classe Scienze Fisiche Matematiche Naturali

Rendiconti

Giorgio Pasquarè, Andrea Zanchi

Cenozoic Volcanism and Tectonics in Western-Central Mexico

Atti della Accademia Nazionale dei Lincei. Classe di Scienze Fisiche, Matematiche e Naturali. Rendiconti, Serie 8, Vol. **78** (1985), n.6, p. 293–301.

Accademia Nazionale dei Lincei

<http://www.bdim.eu/item?id=RLINA_1985_8_78_6_293_0>

Atti della Accademia Nazionale dei Lincei. Classe di Scienze Fisiche, Matematiche e Naturali. Rendiconti, Accademia Nazionale dei Lincei, 1985.

SEZIONE II

(Fisica, chimica, geologia, paleontologia e mineralogia)

Geologia. — *Cenozoic Volcanism and Tectonics in Western-Central Mexico.* Nota di GIORGIO PASQUARÈ (*) e ANDREA ZANCHI, presentata (**) dal Socio A. DESIO.

RIASSUNTO. — Nel presente lavoro vengono analizzati su scala regionale i rapporti esistenti tra vulcanismo calco-alcalino Cenozoico e strutture distensive nell'area di Guadalajara, situata nel Messico centro-occidentale.

Osservazioni di campagna e datazioni assolute hanno permesso di identificare tre principali sequenze vulcaniche.

La più antica è costituita da lave andesitiche e dacitiche messesi in posto durante il Miocene medio, direttamente al di sopra del basamento corrugato mesozoico affiorante nella parte meridionale dell'area. Questa sequenza occupa la posizione posseduta più a Nord dalla serie vulcanica oligocenica della Sierra Madre Occidentale.

La sequenza intermedia, affiorante nella valle del Rio Grande de Santiago ed a Nord di essa, si è originata nel Miocene superiore durante l'impostazione della Provincia Basin and Range, ampiamente sviluppata negli Stati Uniti Occidentali. La sequenza è costituita da potenti successioni di colate di andesiti basaltiche e di ignimbriti, che riempiono graben orientati N-S, sprofondatisi nelle vulcaniti medio-mioceniche.

La sequenza più recente costituisce la parte più occidentale della cintura vulcanica transmessicana (TVB), attivatasi a partire dal Pliocene, e associata in questo settore ad un sistema di graben orientato NW-SE esteso tra Tepic, Guadalajara e Colima e connesso all'apertura del Golfo di California.

Lo spostamento verso Sud al Miocene del vulcanismo Oligocenico della Sierra Madre Occidentale ravvicina quest'ultimo, dal punto di vista sia temporale che spaziale, a quello costituente la cintura vulcanica transmessicana. L'origine di quest'ultima appare pertanto connessa non solo ai fenomeni di subduzione attualmente attivi nella fossa Mesoamericana, ma anche ai movimenti transtensivi che hanno accompagnato lo sviluppo del margine convergente pacifico dal Miocene superiore ad oggi.

1. INTRODUCTION

In the western sector of central Mexico huge amounts of calc-alkaline volcanic materials were erupted from Miocene until recently.

In geological literature these sequences were in part referred to the Tertiary volcanic cycle of Sierra Madre Occidental, and in part to the Plio-quaternary volcanic chain crossing central Mexico, known as the Transmexican volcanic

(*) Dipartimento di Scienze della Terra dell'Università di Milano.

(**) Nella seduta del 28 giugno 1985.

belt (TVB) (Watkins *et alii*, 1971; Demant and Robin, 1975; Demant, 1978; Demant, 1979; Gastil *et alii*, 1979*a*, 1979*b*).

In a previous work (Pasquarè *et alii*, 1985, in print) N—S tensional structures connected with the southern prosecution of " Basin and Range Province " of the western United States were related to the last Sierra Madre Occidental volcanic phase, active during late Miocene, and emphasis was given to NW–SE structures linked with the opening of the Gulf of California. Along these linea-

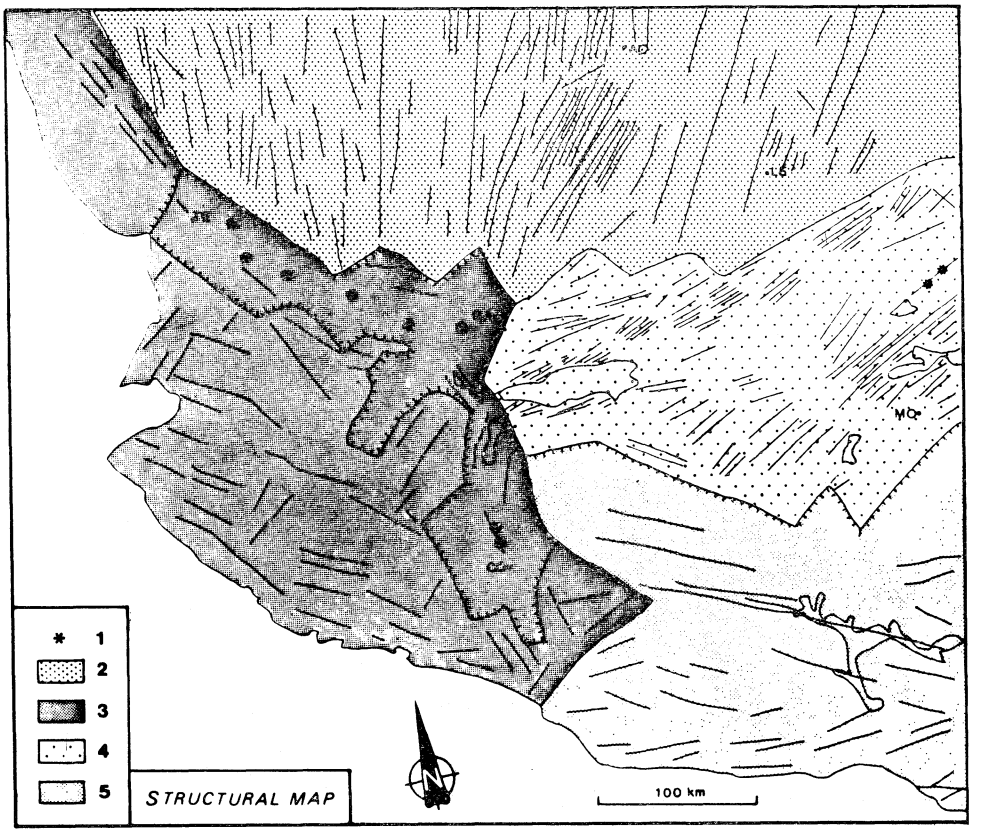

Fig. 1. – Simplified structural map of western–central Mexico: 1) TVB main volcanic centres; 2) Basin and Range Province; 3) Western TVB–Gulf of California Province; 4) Central TVB Province; 5) Sierra Madre del Sur–Rio Balsas Province; TE Tepic; Ga Guadalajara; Co Colima; AC Aguascalientes; Le Leon; Mo Morelia.

ments Pliocene TVB activity took place in the sector among Tepic, Guadalajara and Colima.

Further east, in the TVB central sector, ENE–WSW distensive structures prevail, and are mainly active during Quaternary time (fig. 1).

The aim of this work is to single out, on a regional scale, the relationships between tectonics and volcanism in the area around Guadalajara, where all the previously mentioned structures mutually interact.

2. MORPHOLOGICAL, STRATIGRAPHICAL AND GEOCHRONOLOGICAL CONSIDERATIONS

The position of the studied area, placed where the main structural lineaments of central Mexico intercross, accounts for its complex morpho–structural pattern. The preliminary recognition of the main morphological provinces allowed the identification of the main structural elements and associated volcanic sequences (fig. 2).

The dominant morphological province consists of a graben system, with NW–SE and N–S trending marginal faults. The NW–SE trends prevail between Tepic and Guadalajara, and die out on the southern side of the San Marcos lake; the latter develop between the Sayula lake and Colima.

Plio-quaternary volcano-clastic sequences outcrop within these grabens. Pliocene units mainly consist of ignimbrites whereas dacite and andesite lavas, connected with Quaternary centres, dominate the top of the sequence.

The Rio Grande de Santiago gorge, developed along the NW–SE fault–system, separates the Tepic–Guadalajara graben from the structurally elevated block present in the Northern sector of the area.

This block is composed of a late Miocene sequence of andesite and basalt lava flows, ignimbrites and volcano–clastic products, deeply eroded by Rio Grande de Santiago and by its right–hand tributaries. Most drainage follows fracture trends, but on the whole, this late Miocene sequence maintains a tabular aspect.

The southern margin of the Guadalajara–Tepic graben is segmented in a puzzle–like system of faulted blocks, by the intersection of NW–SE and E–W faults.

The blocks show the oldest stratigraphic sequences of the area, consisting of Mesozoic marine limestones and sandstones intruded by quartz–monzonitic in complexes of Laramide age.

This Mesozoic basement is covered by a thick volcanic sequence referable to Sierra Madre Occidental activity, and emplaced during Middle Miocene.

The morphological and tectonic framework indicates that the Miocene to Quaternary volcanic succession can be separated in sequences having different stratigraphic, volcanological and structural patterns.

Field work was accompanied by K/Ar dating of samples collected by the authors and analyzed in the Geophysical Institute of Neaples University on account of Comision Federal de Electricidad (CFE), Mexico city.

Additional information is available from Watkins *et alii* (1971); Gastil *et alii* (1979); Mahood (1980), from an unpublished report of McEvilly *et alii* (1978) and from unpublished data of CFE.

The oldest recognized volcanic products, overlying the mesozoic basement of the Sierra de Tapalpa, are composed of andesite and dacite lavas, dated 17 m.y.

The sequence is built up by highly fractured plateau–like flow units, forming a high block around the Atemajac village and by other minor tilted blocks in

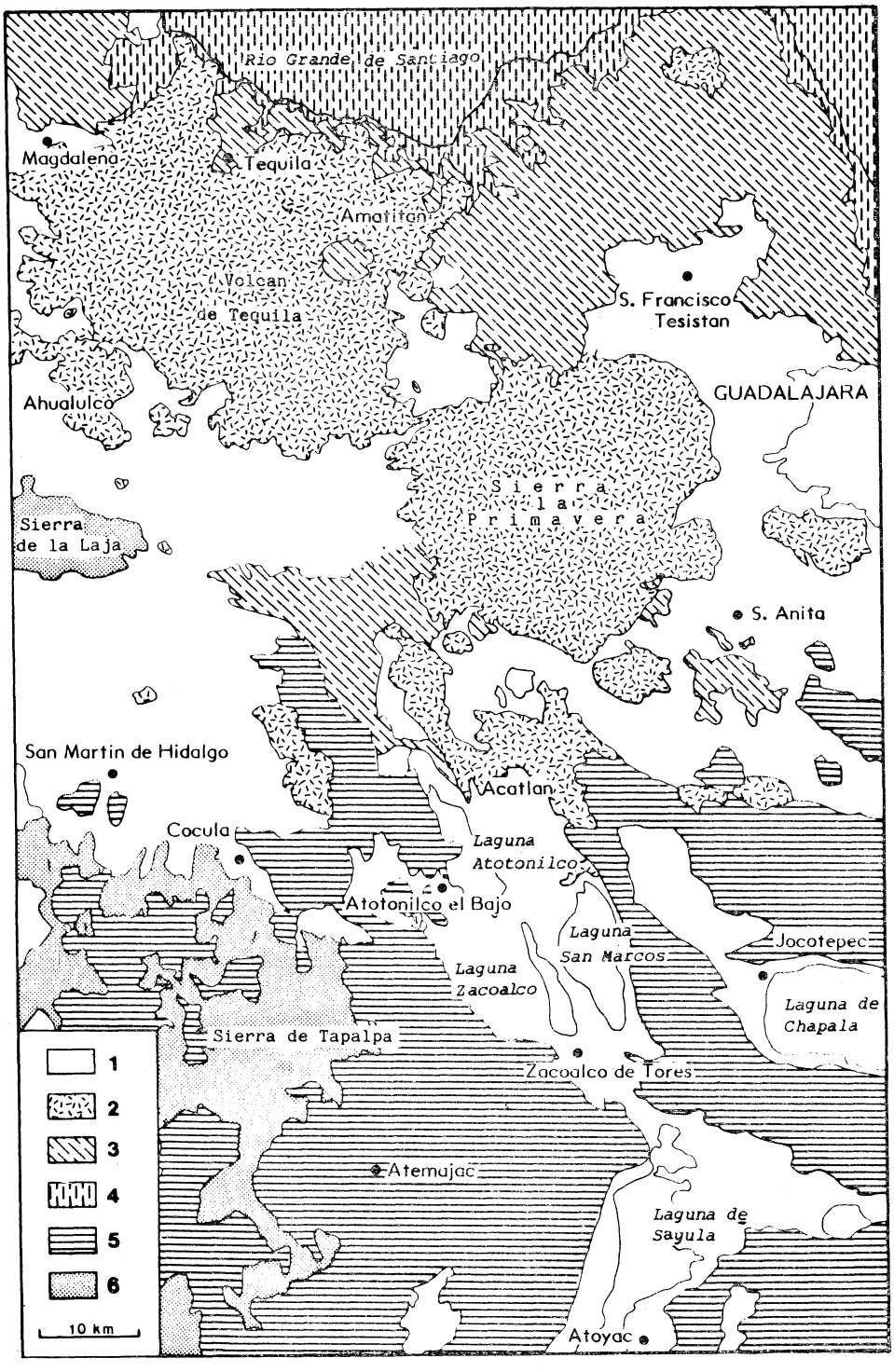

Fig. 2. – Geological Map of Guadalajara Area: 1) Quaternary sediments Californian graben filling; 2) Quaternary volcanics Californian graben filling; 3) Pliocene volcanics Californian graben filling; 4) Late Miocene volcanics: Basin and Range graben filling; 5) Middle Miocene volcanics; 6) Cretaceous basement.

the southern part of the area. These blocks emerge from the Plio-quaternary sub–horizontal volcano–sedimentary sequence filling the recent grabens.

Northwest of Guadalajara, in the Rio Grande de Santiago section described by Watkins *et alii* (1971), a 500 m thick sequence, composed of rhyolitic ignimbrites and basalt lava flows, shows K/Ar ages between 9,5 and 8,7 m.y.

It can be correlated with the succession observed by the authors along the Rio Grande de Santiago and the Rio Verde E of Guadalajara (fig. 3). Here the section is made up by basaltic–andesite tabular lava flows, containing thick breccia beds with the same composition. Acidic lavas and ignimbritic horizons mainly top the sequence.

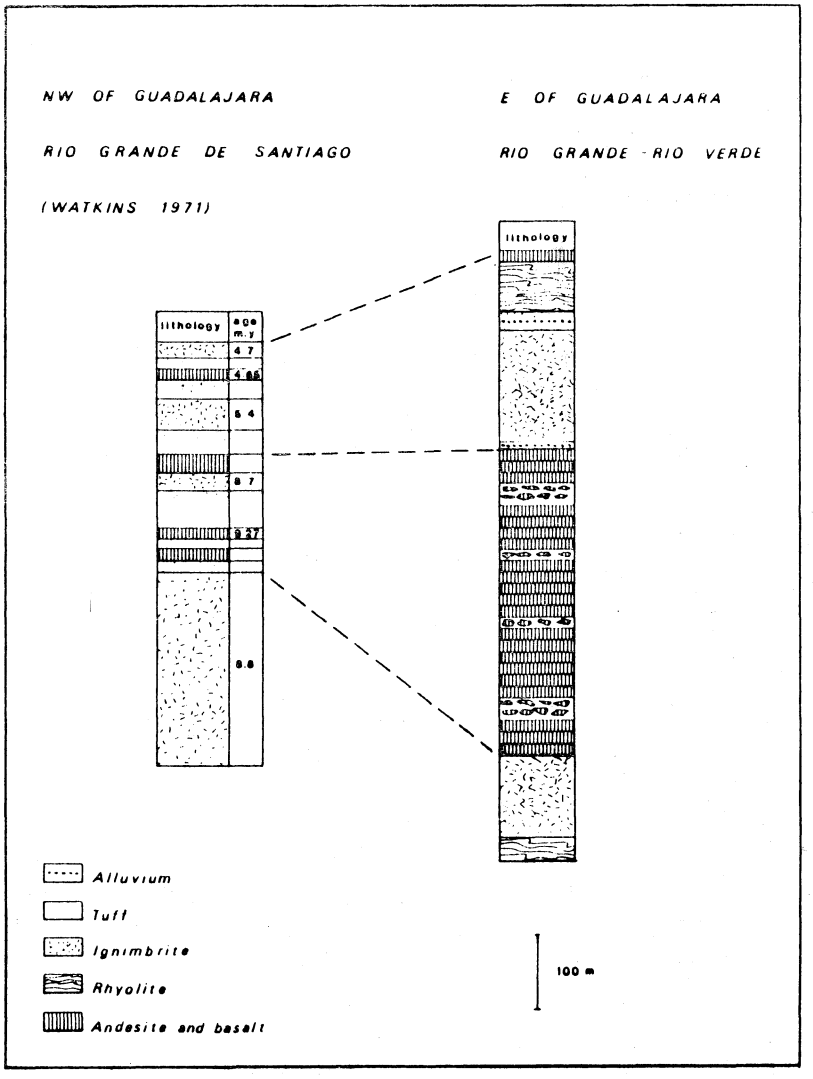

Fig. 3. – Stratigraphic sections.

A 3 m.y. time break separates these levels from another lavas and ignimbrites sequence, dated from 5.5 to 2.1 m.y., which constitutes both the upper part of the plateau flanking the left side of the Rio Grande de Santiago valley and the bottom of the Tepic–Guadalajara graben.

This clearly bimodal sequence is composed of dacite and rhyolite lavas and acid ignimbrites, intercalated with basalt and basic ignimbrites and continues during Quaternary, forming many volcanic centres aligned near the central portion of the graben system.

Near Guadalajara the beginning of Quaternary activity is characterized by andesite–basalt fissural eruptions, varying in age between 1.2 and 0.9 m.y., whose products outcrop nearby Amatitan.

This Pleistocene volcanism is followed by the andesites and ignimbrites of Acatlan, comprising the San Marcos lavas, dated 0.8 m.y.

The dacitic products of the Volcan Tequila, dating around 0.6 m.y., follow. The rhyolites of Agua Dulce area have radiometric ages of 0.3 m.y. and precede the extensive activity of La Primavera complex. The emplacement of the latter complex belonging to La Primavera activity, was accomplished between 0.1 and 0.025 m.y. ago (Mahood, 1980).

3. Discussion

The available data show that volcanic calco–alkaline activity began about 17 m.y. ago and continued in the Guadalajara area until recently (fig. 4). This volcanic succession can be separated by two time breaks in three main stratigraphic sequences, which were affected by decreasing tensional deformations with decreasing ages.

The Tertiary volcanic sequences show a spatial continuity with Cenozoic volcanics present in western U.S.A. and northwestern Mexico, in spite of the remarkable chronological differences.

In the Mexican States of Sinaloa, Chihuahua and Durango, large calco–alcaline plateau lavas and welded tuffs, forming the upper part of Sierra Madre Occidental activity, were erupted before the beginning of Miocene.

Their relative ages are not generally younger than 27 m.y. with some isolated data up to 23 m.y. (Cameron *et alii*, 1980; McDowell and Keizer, 1977; McDowell and Clabaugh, 1979; Swanson *et alii*, 1978).

The youngest Cordilleran calc-alkaline volcanism of the southwestern United States is concentrated between 28 and 22 m.y. ago in Arizona, between 27 and 21 m.y. ago in southern California, between 28 and 20 m.y. ago in the western Great Basin of Nevada; older ages up to 40 m.y. characterize the Cenozoic magmatic activity of central–eastern Great Basin and southwestern New Mexico (Armstrong, 1970; Christiansen and Lipman, 1972; Lipman *et alii*, 1972; McKee, 1971; Coney and Reynolds, 1977; Stewart and Carlson, 1978).

Nevertheless, the strong analogies of structural and geochemical features existing between the forementioned sequences point out a common genesis

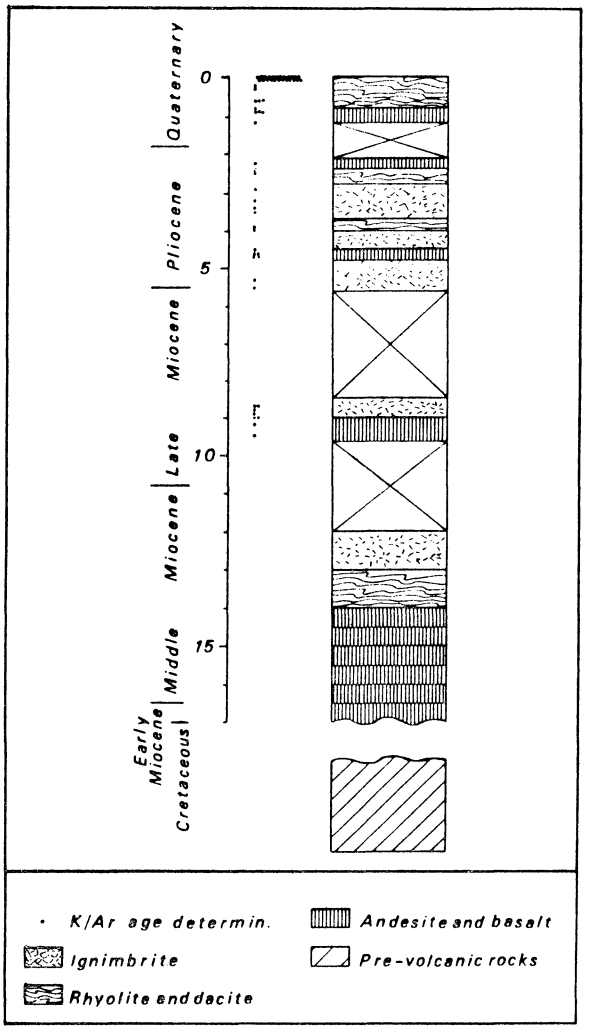

Fig. 4. – Geochronology of the main volcanic sequences.

connected with geodynamical phoenomena interesting the Pacific convergent margin during Tertiary time.

The oldest of the three sequences, recognized in the Guadalajara area, represents the southward prosecution of Sierra Madre Occidental calco–alkaline volcanism, which followed the emission of the Oligocene ignimbrites and basalts belonging to the Upper Volcanic Supergroup (Swanson and Clabaugh, 1979).

Moreover this sequence partly correlates with the andesites of the Comondù formation outcropping in Baja California, ranging in age between 24 and 12 m.y. (Hausback, 1984; Sawlan *et alii*, 1984) and preceding the opening of the Protogulf of California.

The late Miocene sequence shows a structural and temporal connection with the distensive movements associated with the " Basin and Range Province " of the western United States, which affected western Mexico during the same period and represents the filling of a N–S trending graben system developed within Middle Miocene volcanics.

These tensional events caused the opening of the Protogulf of California 10 m.y. ago (Colletta and Angelier, 1983).

The NW–SE graben system in which the Plio–quaternary Transmexican Volcanic Belt develops, has the same trends of the wrench faults characterizing the structural reorganization of the Gulf of California, occurred since early Pliocene (Colletta and Angelier, 1983).

Most of the Quaternary activity occurs within these tectonic depressions and is aligned along the same NW–SE lineaments, showing a strong reactivation of these until recent times.

In conclusion, the time–space progressive southward migration of Sierra Madre Occidental volcanism indicates a clear approach to Plio–quaternary TVB activity.

Moreover these two volcanic provinces appear to be structurally interconnected and genetically related to transtensive movements affecting the Pacific Cordilleran margin of western Mexico since late Miocene.

This remark questions the existence of a simple genetical and structural connection between the TVB and the subduction taking place in the Meso–American trench, as on the other hand many previous authors have suggested (Demant and Robin, 1975; Cantagrel and Robin, 1979; Demant, 1979; Karig *et alii*, 1978; Schurbet and Cebull, 1983).

References

Armstrong R.L. (1970) – *Geochronology of Tertiary igneous rocks, eastern Basin and Range Province, western Utah, eastern Nevada and vicinity, U.S.A.* « Geol. Soc. Am. Bull. », *81*, 3513-3536.

Cameron K.L., Cameron M., Bagby W.C. and Moll E.J. (1980) – *Petrologic characteristics of mid-Tertiary volcanic suites, Chihuahua, Mexico.* « Geology », *8*, 87-91.

Cantagrel J. and Robin C. (1979) – *K-Ar dating on eastern Mexican volcanic rocks-relations between the andesitic and the alkaline provinces.* « Journ. Volc. Geoth. Res », *5*, 99-114.

Christiansen R.L. and Lipman P.W. (1972) – *Cenozoic volcanism and plate tectonic evolution of the western United States.* II: *Late Cenozoic.* « Roy. Soc. Loud. Philos. Trans. », Ser. A, *271*, 249-284.

Colletta B. and Angelier J. (1983) – *Tectonique cassante du nord–ouest Mexicain et ouverture du Gulf of California.* Popoff M. et Tiercelin J.J. eds., *Rifts et fosses anciens : Tectonique–volcanisme–sedimentation. apports de l'actualis*, 433-441.

Coney P.J. and Reynolds S.J. (1977) – *Cordilleran Benjoff zones.* « Nature », *270*, 403-406.

Demant A. and Robin C. (1975) – *Las Fases Del Volcanismo En Mexico : Una Sintesis En Relacion Con La Evolucion Geodinamica Desde El Cretacico.* « Revista Inst Geol. U.N.A.M. », *1*, 70-73.

DEMANT A. (1978) – *Caracteristicas Del Eje Neovulcanico Transmexicano y Sus Problemas de Interpretacion.* « Revista Ins. Geol. U.N.A.M. », *2* (2), 172-187.

DEMANT A. (1979) – *Volcanologia Y Petrografia Del Sector Occidental Del Eje Neovolcanico.* « Revista Ins. Geol. U.N.A.M. », vol. *3* (1), 39-57.

GASTIL G., KRUMMENACHER D. and JENSKY W.A. (1979) – *Reconnaissance Geology of west–central Nayarit, Mexico : summary.* « Geol. Soc. Am. Bull. », *80*, 15-18.

GASTIL G., KRUMMENACHER D. and MINCH J. (1979) – *The record of Cenozoic volcanism around the Gulf of California.* « Geol. Soc. Am. Bull. », *90*, 839-857.

HAUSBACK B.P. (1984) – *Cenozoic Volcanic And Tectonic Evolution of Baja California Sur, Mexico.* In FRIZZELL (1984), *Geology of the Baja California Peninsula : Pacific Section*, « S.E.P.M. », *39*, 219-236.

KARIG D.E., CARDWELL R.K. and MOORE D.F. (1978) – *Late Cenozoic Subduction And Continental Margin Truncation Along The Northern Middle American Trench.* « Geol. Soc. Am. Bull. », *89*, 265-276.

LIPMAN P.W., PROSTKA H.J. and CHRISTIANSEN R.L. (1972) – *Cenozoic volcanism and plate tectonic evolution of western United States.* I: *Early and Middle Cenozoic.* « Roy. Soc. Lond. Philos. Trans. », ser. A, *271*, 217-248.

MAHOOD G.A. (1980) – *Geological evolution of a rhyolitic center– Sierra la Primavera, Jalisco, Mexico.* « Journ. Volc. Geoth. Res. », *8*, 199-230.

MCDOWELL F.W. and KEIZER R.P. (1977) – *Timing of mid–Tertiary volcanism in the Sierra Madre Occidental between Durango and Mazatlan, Mexico.* « Geol. Am. Soc. Bull. », *88*, 1479-1487.

MCDOWELL F.W. and CLABAUGH S.E. (1979) – *Ignimbrites of the Sierra Madre Occidental and their relation to the tectonic history of Western Mexico.* « Geol. Soc. Am. », Sp. Paper, *180*, 113-124.

MCEVILLY T.V., MAHHOD G.A., MAJER E.L., SCHECHTER B. and TRUESDELL A.H. (1978) – *Seismological–geological field study of the Sierra La Primavera geothermal system.* Univ. of California, Berkeley dept. of Geology and Geophysics, prelim. rep., 1-13.

MCKEE E.H. (1971) – *Tertiary Igneous Chronology of the Great Basin of Western United States – Implications for Tectonic Models.* « Geol. Soc. Am. Bull. », *82*, 3497-3502.

PASQUARÈ G., VEZZOLI L. and ZANCHI A. (1985) – *Morphological and Structural Model Of Transmexican Volcanic Belt.* « Geoph. Intern. ». (In print).

SAWLAN M.C. and SMITH J.C. (1984) – *Petrologic Characteristics, Age and Tectonic Setting of Neogene Volcanic Rocks in Northern Baja California Sur, Mexico.*

FRIZZELL V.A. (1984) – *Geology of Baja California Peninsula : Pacific Section*, « S.E.P.M. », *39*, 237-251.

SCHURBET D.H. and CEBULL S.E. (1984) – *Tectonic Interpretation of the Transmexican Volcanic Belt.* « Tectonophisics », *40*.

STEWART E.R. and CARLSON J.E. (1978) – *Generalized maps showing distribution, lithology and age of Cenozoic igneous rocks in the Western United States.* « Geol. Soc. Am. Mem. », *152*, 1-31.

SWANSON E.R., KEIZER R.P., LYONS J.I. and CLABAUGH S.E. (1978) – *Tertiary volcanism and caldera development near Durango City, Sierra Madre Occidental, Mexico.* « Geol. Soc. Am. Bull. », *89*, 1000-1012.

WATKINS N.D., GUNN B.M., BAKSI A.K., YORK D. and ADE–HALL J. (1971) – *Paleomagnetism, Geochemistry and Potassium–Argon Ages of the Rio Grande de Santiago Volcanics, Central Mexico.* « Geol. Soc. Am. Bull. », *82*, 1955-1968.