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Age and origin of the "Mexican Onyx" at San Antonio Texcala (Puebla, Mexico)

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Abstract

A great variety of color banded $CaCO_3$ is known as „Mexican Onyx", and is extensively used for ornamental purposes. Within the San Antonio Texcala mining district an area of about 24.000 m^2 is covered by a thick travertine crust with a calculated volume of at least 2,8 x 10^6 t. It originates from warm waters that emerge on young fissures and faults. It seems to be likely that the travertine formation is related to the hydrothermal activity of the Transmexican Volcanic Belt and to the seismicity of this zone. The deposit is built up by different travertine varieties. The main lithotypes are: (1) dense crystalline laminated travertine; (2) ray crystal travertine; (3) shrub layer travertine; (4) irregular porous travertine; (5) travertine breccia. Textural variation seems to be related to water temperature/distance from the emergence point, rapid or slow degassing of CO_2 and bacterial influence. At the moment, a light green banded variety (native sulfur impurities) is mined. It is the facture fill of a morphological prominent fissure-ridge travertine. U/Th data indicate, that the travertine has been deposited since at least 52 $\pm$ 5 ka.

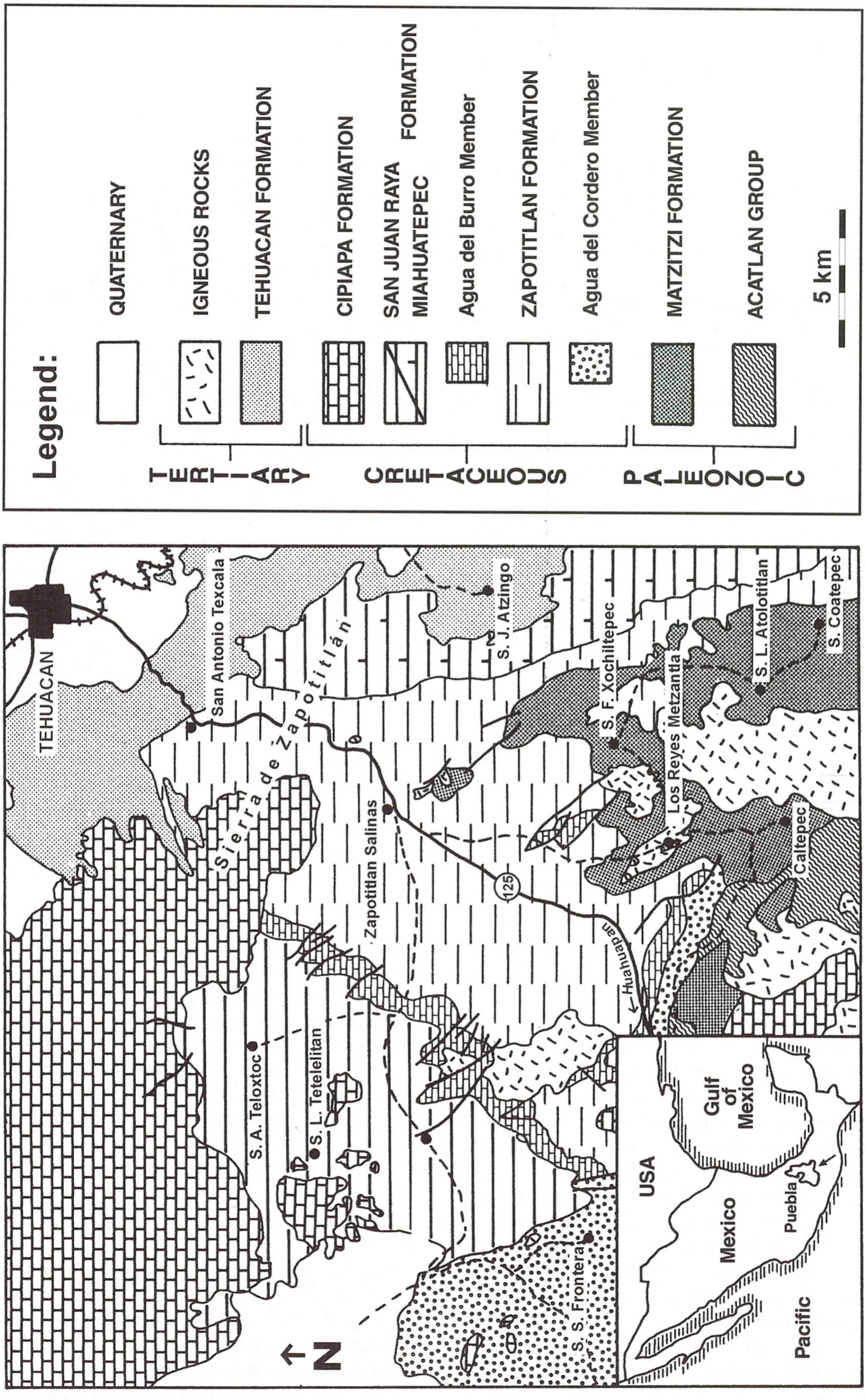
Keywords: travertine, volcanism, Mexico, hydrothermal deposition, Pleistocene

INTRODUCTION

„Mexican Onyx" is a well known gemstone or semi-precious stone used extensively for ornamental and building purposes. Figurines of that material are very popular all over Middle and North America. It is also carved into vases, bookends (Fig.3/2), chess sets plates, obelisks, pyramids, and statues. It was even widely used in pre-conquest Mexico for masks and other artifacts and the Spanish also liked the stone so that many old churches in Mexico are decorated with it, carved into statues and pulpits. Beautiful thin translucent pieces have served as windows before the use of industrial glass.

The term Mexican „onyx" is misleading. Mineralogically, „onyx" is used to name parallel banded and colored deposits of calcedonia (Kösler, 1991). By contrast, the gemstone industry uses the term „Mexican Onyx" to name a variety of calcium carbonate formed as traver-tine or tufa with impurities causing it to exhibit beautiful color banding (Cardenas Vargas, 1993). The Nahuatl name „Tecali" is also used in Mexico because large deposits of Mexican Onyx were early found near the village of Tecali, Puebla.

To raise up confusion, Mexican Onyx is also sold and described as „onyx marble". So, we find information about the great variety and distribution of Mexican Onyx, connected with some mining and economic aspects, within the book about „marmoles de México (Cardenas Vargas, 1993). The controversal terminology demonstrates the lack of detailed knowledge. Despite the fact that Mexican Onyx is very popular and well



Legend:
TERTIARY
QUATERNARY
IGNEOUS ROCKS
TEHUACAN FORMATION
CRETACEOUS
CIPIAPA FORMATION
SAN JUAN RAYA FORMATION
MIAHUATEPEC FORMATION
Agua del Burro Member
ZAPOTITLAN FORMATION
Agua del Cordero Member
PALEOZOIC
MATZITZI FORMATION
ACATLAN GROUP
5 km
TEHUACAN
San Antonio Texcala
Sierra de Zapotitlán
S. J. Atzingo
S. F. Xochiltepec
Los Reyes Metzantla
S. L. Atolotitlan
S. Coatepec
Zapotitlan Salinas
125
Caltepec
Huahuapan
S. A. Teloxtoc
S. L. Tetelelitan
S. S. Frontera
N
USA
Gulf of Mexico
Mexico
Puebla
Pacific

known among gemmologists, no modern scientific information is available in literature. There are only some short reports from the end of the 19th century (Barcena, 1874, 1876; Anonymous, 1894) and the beginning of the 20th century (Lawton, 1910). More recently Ford & Pedley (1996) in their review of tufa and travertine deposits refer to the confusion about the term „Mexican Onyx" and conclude that at least some of the ornamental „onyx" seems to be flowstone from speleothems or travertine. Within the mining geology monograph of the State of Puebla (Galván Villarreal & Martínez Vera, 1995) tecali, marble and onyx of the Tehuacan region are listed as chemical deposits and it is considered, that tecali may only be a variety of travertine. Travertine deposits near the city of Puebla are described by Erffa et al. (1977) with some detail.

GEOLOGICAL SETTING

The San Antonio Texcala district is situated in the southernmost part of the State of Puebla (Fig. 1).This region belongs to the Sierra Madre del Sur morphotectonic province that is limited to the north by the Trans-Mexican Volcanic Belt (e.g. de Cserna , 1989). Part of that morphotectonic province, situated west of the line Tehuacan-Oaxaca is also known as Tlaxiaco basin or Tlaxiaco province (Lopez Ramos, 1981). In terms of modern tectonostratigraphy and terrane interpretation it may be attributed to the Mixteco terrane (area Zapotitlán-Tlaxiaco; Moran Zenteno, 1984) or to the Zapoteco terrane (Ortega-Gutierrez et al., 1990; Sedlock et al., 1993).

San Antonio Texcala is situated about 10 km southwest of the city of Tehuacan. It is linked to Tehuacan as well as to Zapotitlán Salinas and to Huahuapan de León, State of Oaxaca by Mexican Highway 125. The mining area is located between about 1700 m and 1800 m above sea level. It forms part of the Sierra de Zapotitlán, a northwest-southeast striking mountain range limited to the east by the depression of the Tehuacan valley. The basement rocks of the early Paleozoic Acatlan Group and the Pennsylvanian Matzitzi Formation are exposed about 10 km south of San Antonio Texcala (Fig. 2). The higher parts of the Sierra are built up by thick Cretaceous limestone packages. Immediately west of San Antonio Texcala marls and sandstones of the Zapotitlan Formation, thick rudist-bearing limestones of the San Juan Raya and Cipiapa Formations, all Cretaceous in age, are exposed. To the east of the village the limnic-terrestrial sedimentary rocks of the Tertiary Tehuacan Formation are found.

Fig. 1 (opposite page): - Simplified geological map of the Tehuacan-Huahuapan area in southern Mexico. The study area is situated near the village of San Antonio Texcala.

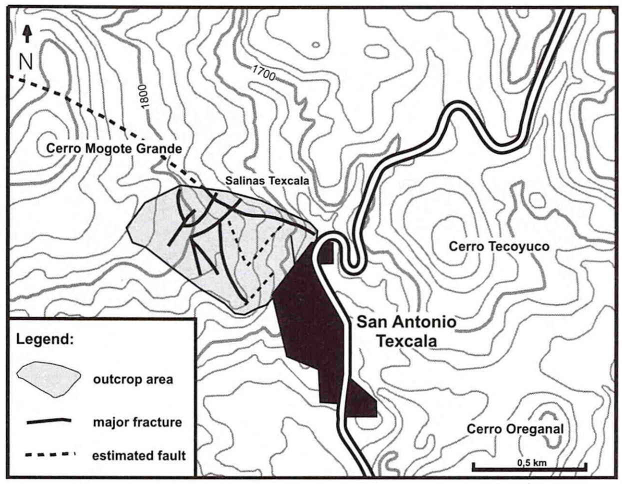


Fig. 2: - Map of the San Antonio Texcala area with outcrop limits of thick travertine (> 1 m). A main fracture system is clearly traced by the open pits of former and recent mining of dense fissure travertine.

THE MINING AREA

In the San Antonio Texcala area Mexican Onyx is exploited and worked since more than one hundred years. It is a relatively local and restricted deposit in comparison with other occurences of Mexican Onyx (States of Oaxaca, Coahuila, Durango, San Luis Potosí, Guerrero: Cardenas Vargas, 1993). Today more than about 120 workers with their families earn their living with that material (Fig. 3/1,3). In the San Antonio Texcala mining district a several meter thick travertine crust with a calculated volume of at least 2,8 x 10^6 t covers a preexisting landscape morphology developed on Cretaceous and Tertiary sedimentary rocks within an area of about 24.000 m^2 (Fig. 2). The thick crust exhibits a rather abrupt termination downslope, at the edge of the village and in the creek to the north. To the northwest upslope towards the Cerro Mogote Grande the crust pinches out at about 1840 m above sea level. The travertine formes slopes and terraces of different scale (several meters down to cm-sized microterraces) and even cascade and waterfall travertine is Fig 3/4). However, intensive quarrying during the past decades has disturbed much of the original morphology.

The deposit is built up by dense crystalline travertine and porous tufa. The more porous variety is easily worked and thus used as a building stone. However, recent exploitation focuses on the dense crystalline

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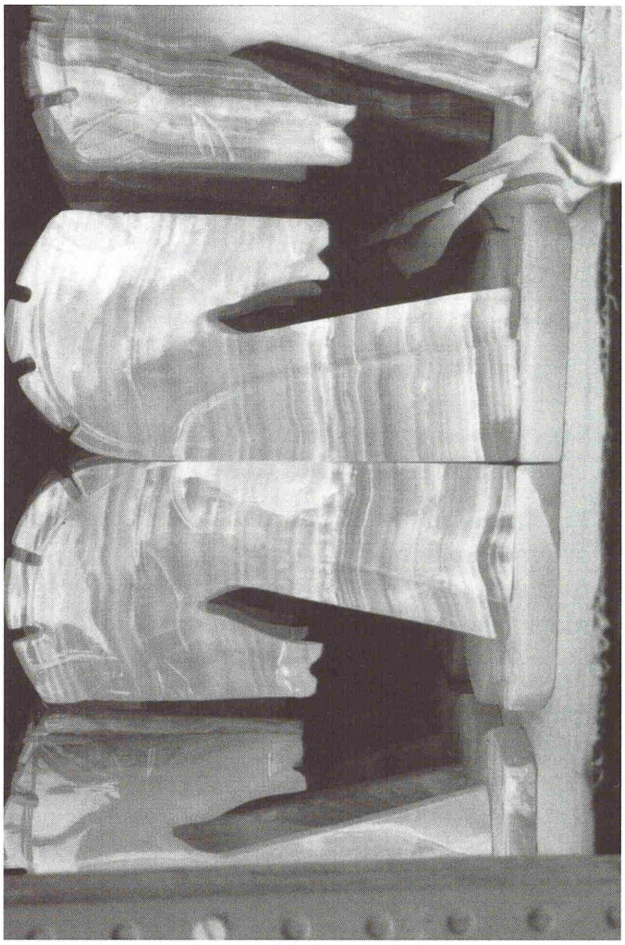

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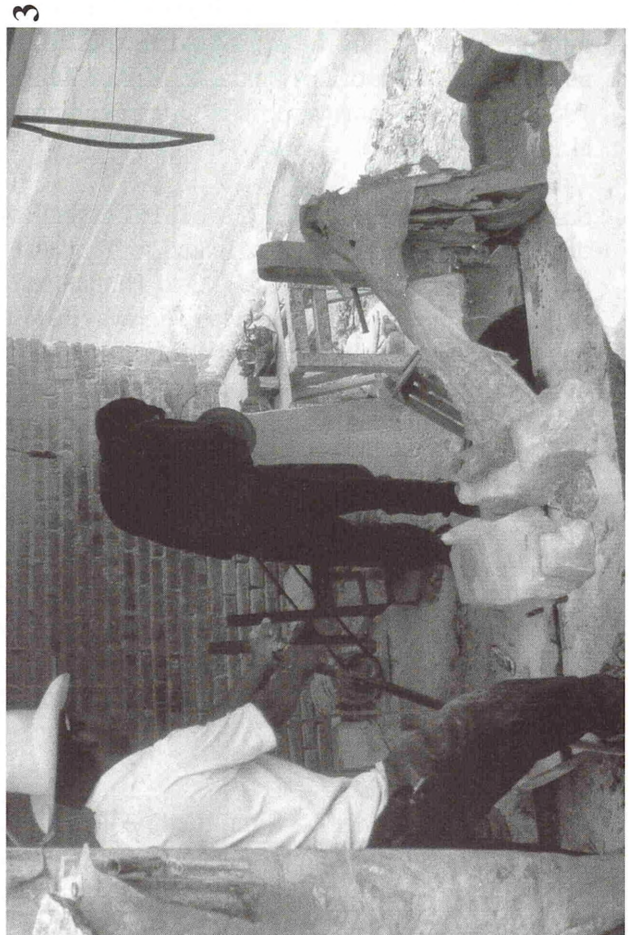

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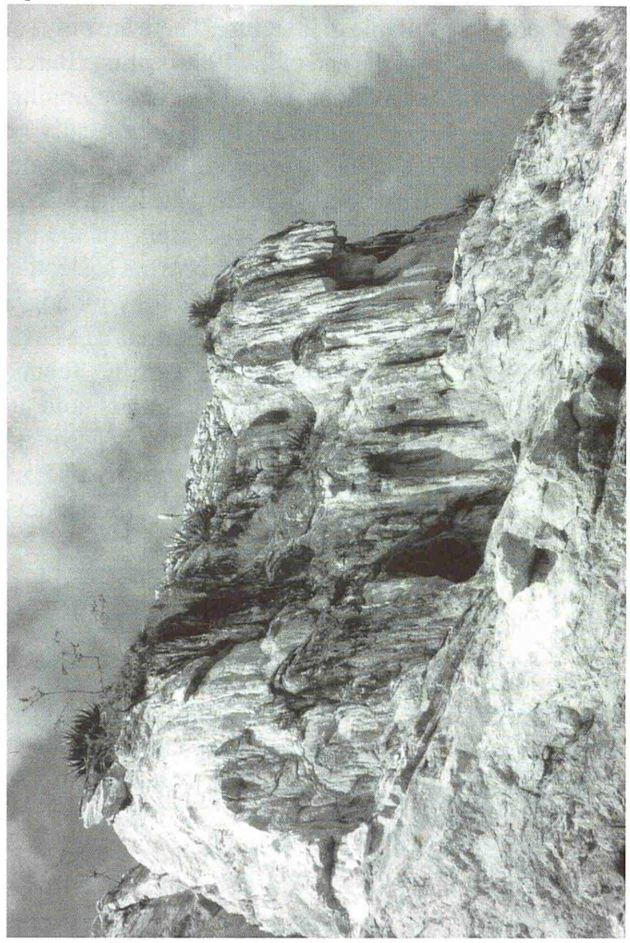

varieties for the more precious handcraft works. Most actual working pits are situated on a prominent NW-SE directed whale back-like ridge (Fig. 4/1,2). The travertine is detached by blasting causing considerable loss of valuable raw material. The wrong use of explosive threatens the ressources like in other comparable mexican deposits, too (Cardenas Vargas, 1993). Larger blocks are pre-crushed and then transported to the manufacturing plants by pickups or small trucks.

TRAVERTINE LITHOTYPES

Most of the carbonate constituting the San Antonio Texcala travertine is calcite. However, staining by use of Feigl´s solution in the outcrops shows that recently precipitated carbonate is aragonite and not calcite (aragonite turns black with Feigl´s solution whereas calcite remains colorless). It is suggested by Jones & Renaut (1996) that in many cases aragonite is the original precipitate of thermal springs but that it is lost by transformation into calcite. So, it may also be assumed that many if not all travertine carbonate at San Antonio Texcala was originally precipitated as aragonite.

In the study area at least five travertine lithotypes can macroscopically be distinguished: (1) dense crystalline laminated travertine; (2) ray cystal travertine; (3) shrub layer travertine; (4) irregular porous travertine; (5) travertine breccia. However, these are only the main lithotypes or end members and additional subordinated or transitional lithologies may easily be defined.

Dense crystalline laminated travertine

This lithotyp consists of dense fine mm-laminated calcite. Lamination is generally conspicuous because of variations in coloring. The fine laminated travertine forms irregular and wavy layers at a cm scale and even cauliflower structures. It is commonly associated with other lithotypes forming thin intercalations. Interbedded with ray crystal travertine it forms thick packages (Fig.4/3). It seems to be best developed on slopes and cliffs and as fracture fill and is also a main constituent of the prominent fissure ridge.

It is suggested here, that the fine laminated travertine represents rather rapid precipitation as may be expected from water running down on inclined surfaces or on fracture walls. In this case inorganic processes are dominant for carbonate precipitation particularly cooling and the rapid degassing of CO_2 (Chafetz & Folk, 1984).

Ray crystal travertine

One of the most common lithotypes at San Antonio Texcala is the so-called ray crystal travertine (Chafetz & Folk, 1984; Folk et al., 1985). It consists of dense crystalline crusts formed by elongate calcite crystals orientated perpendicular to the depositional surface. These crust show thicknesses of some centimeters to a few tens of centimeters. Layering may be irregular and commonly display cone-shape or radiating pattern. Individual layers are separated from each other by thin detrital interbeds or by fine laminated travertine (Fig. 4/3). In general this travertine lithofacies is strongly suggestive of crystalline selenitic gypsum known as „grass-like“ gypsum from Tertiary evaporites of Sicily (e.g. Schreiber & Decima, 1976) and Spain (e.g. Michalzik, 1996).

It seems to be likely that the ray crystals crystallized directly from solution growing upward from the surface on which they nucleated. A rather rapid crystal growth can be assumed because they are also found on sloping surfaces. It is suggested by Folk et al. (1985) and Guo & Riding (1998) that crusts of ray crystals reflect rapid precipitation in agitated environments with rapid degassing of CO_2. However, in some cases a diagenetic overgrowth must be considered where individual cystals cut through interbeds. Ray crystals of one or two meters that have been reported by Folk et al. (1985) from central Italy may also fall in this category because they are

Fig. 3 (opposite page): -

(1) Arts and crafts shop at the entrance of San Antonio Texcala village.

(2) Bookends made of fine banded to laminated Mexican Onyx of San Antonio Texcala.

(3) Sawing and polishing of the light green variety of Mexican Onyx.

(4) Cascade or waterfall travertine at the NE side of the main fissure ridge.

Fig. 4 (next page): -

(1) Whale back-like fissure-ridge travertine, the main present exploitation zone of the San Antonio Texcala district.

(2) Rustic mining techniques, northern part of the fissure-ridge.

(3) Dense laminated travertine interbedded with ray crystal travertine.

(4) Multiple layers of shrub travertine with interlayers of fine laminated travertine or thin micritic carbonate.

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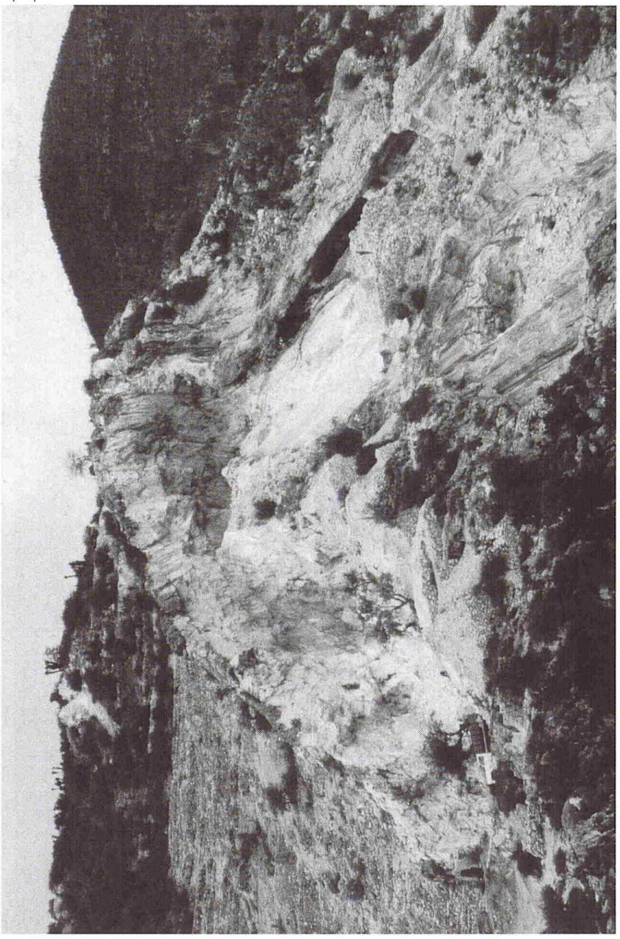

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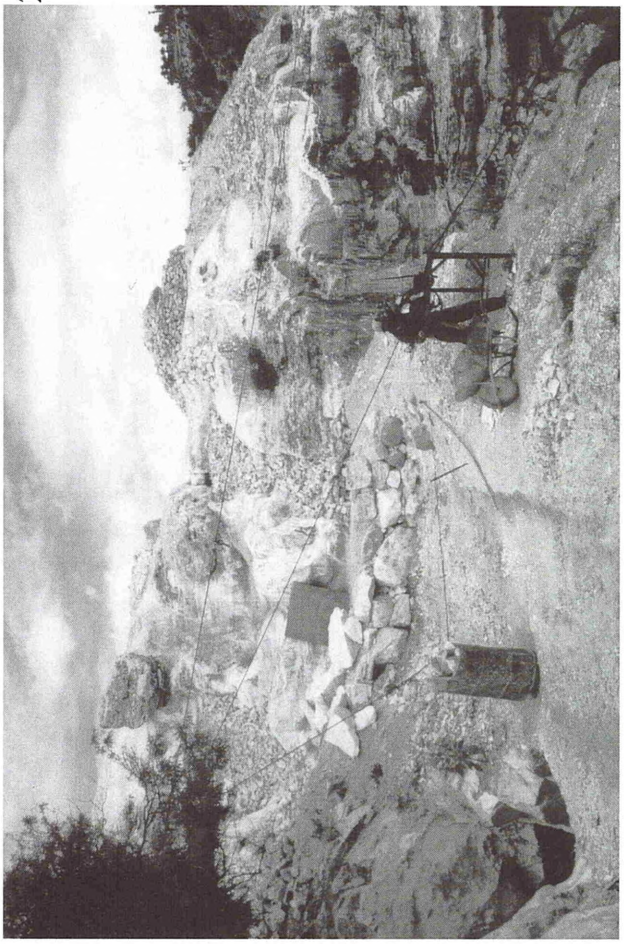

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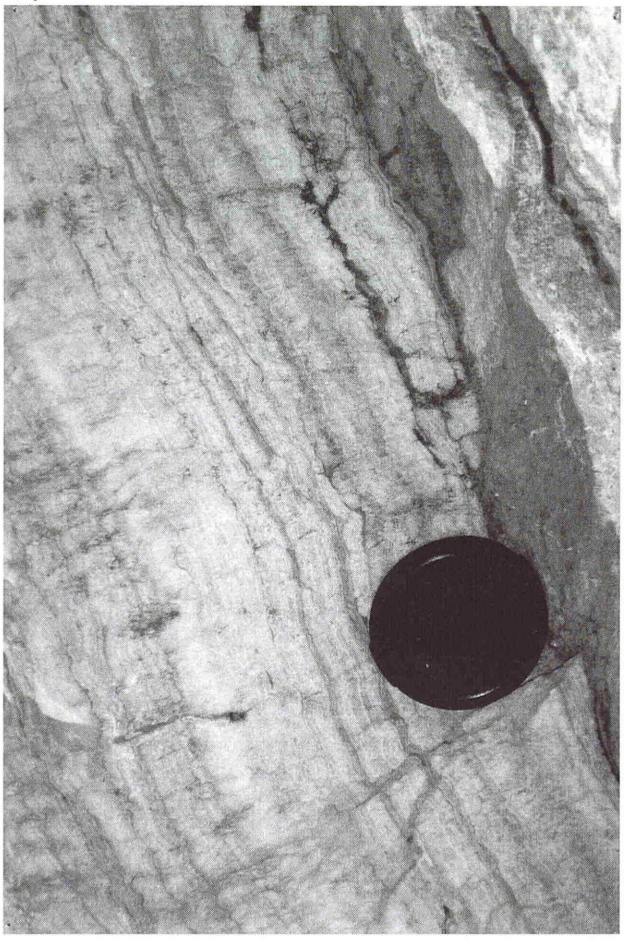

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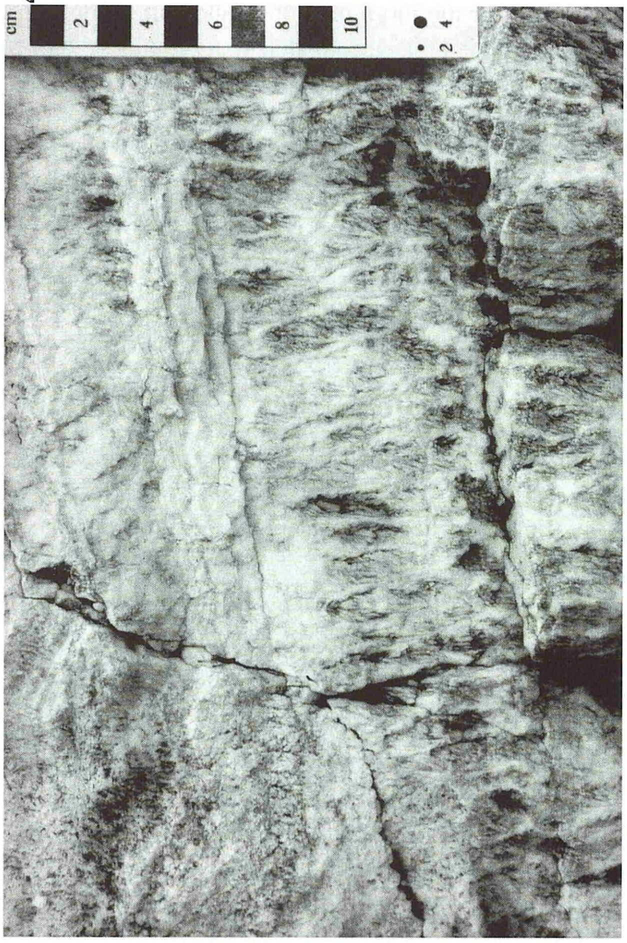

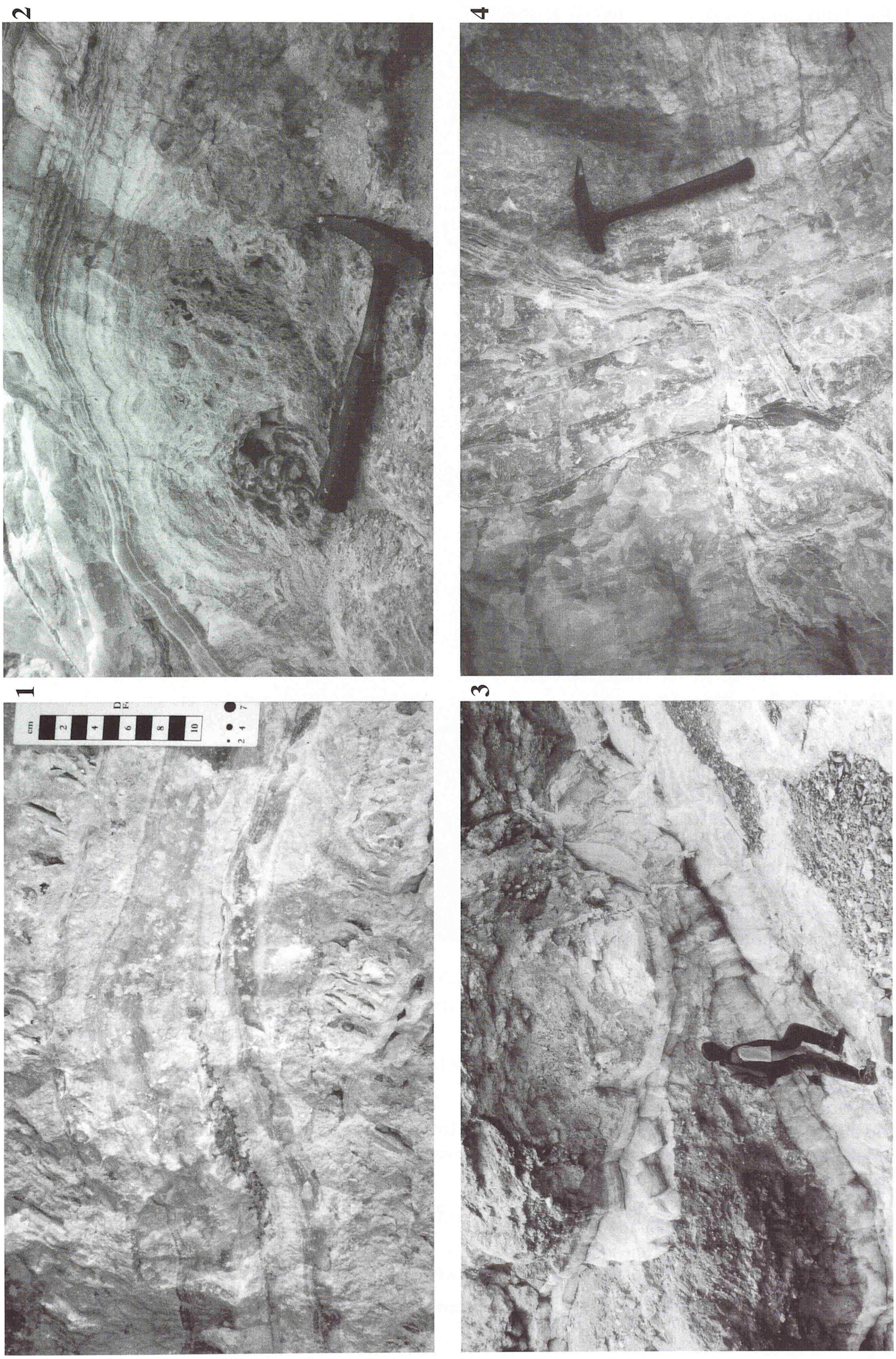
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Fig. 5 (previous page): -

(1) Irregular porous or „paper-thin raft“ travertine with thin laminated interlayers.

(2): Larger cavities with irregularly swirled calcite that resemble spelean deposits.

(3): Thick slope breccia with intercalations of bedded crystalline travertine.

(4): Three generations of travertine formation in the central part of the ridge.

similar to some giant early diagenetic selenite crystals observed in the Messinian of SE Spain.

SHRUB LAYER TRAVERTINE

A remarkable feature of the San Antonio Texcala travertine is the occurrence of porous shrublike layers. Individual layers are some centimeters thick with irregular dentritic morphology. In most cases they look like rows of small trees or shrubs branching upward (Fig. 4/4). They are arranged in multiple layers separated from each other by thin ray crystal horizons, fine laminated travertine or thin micritic carbonate. Fresh cuts of the shrubs are chalky white and powdery.

Different morphologies and field occurrences of shrub travertine have been described by Chafetz & Folk (1984), Chafetz et al. (1998) and Guo & Riding (1994, 1998). Both microbially induced and purely abiotic origins have been proposed. It is suggested by Guo & Riding (1998) that the micrite is essentially formed under microbial influence while crystalline spar in the shrub is of inorganic precipitation. However, there is a general consent that shrub travertine forms in pools, depressions or flat lakes with minor water agitation.

Irregular porous travertine

In several places of the San Antonio Texcala outcrops cavity-rich layers of travertine can be observed. Within this lithotype pores and cavities of mm size up to several cm are developed. In some cases this fabric may be related to plant encrustation. In other cases these are the unfilled holes between tabular calcite pieces orientated parallel or crosswise in relation to the surface (Fig. 5/1). The irregular porous travertine looks much like the paper-thin raft travertine of Guo & Riding (1998, see also Folk et al., 1985) In some larger cavities irregularly swirled calcite can be found that resemble spelean deposits (Fig. 5/2).

The encrusting type as well as the spelean type can be interpreted as precipitated from running water. On the other hand the „paper-thin rafts“are interpretated to have formed at the water surface of stagnant pools (Guo & Riding, 1998). Disturbance breaks the sheets into irregular fragments that were accumulated on the pool floors.

TRAVERTINE BRECCIA

Thick packages of breccia are found especially on the lower slopes of the San Antonio Texcala deposit. It forms layers of up to some tens of centimeters inter-bedded with other travertine lithofacies. The breccia show fan-like morphology thinning out upslope (Fig. 5/3). It mainly consists of angular lithoclasts of all size from the above mentioned travertine lithotypes. The lithoclasts are cemented by pedogenic calcrete with typical nodular or pisoidal textures. Travertine breccia is also found as thin interlayers at the upper slopes and as fracture fill.

The breccia is formed by erosion and gravitational slumping of layered travertine. Travertine rockfall below overhanging cliffs and waterfalls may also contribute part of the lithoclasts. Breccia formation may be related to time intervalls with minor travertine precipitation or displacement of the spring zone. It may also be considered that seismic activity has caused some gravitational mass transport.

ORIGIN, AGE INTERPRETATION AND DISCUSSION

The travertine and tufa of San Antonio Texcala seems to have originated from warm waters that emerge at young fissures and faults, as they do it at the locality until today. Textural variation (dense crystalline laminated, ray crystals, shrub layers, irregular porous) seems to be related to water temperature (e.g. cooling with increasing distance from the emergence point), rapid or slow degassing of CO_2 (e.g. due to the slope), and bacterial influence. Syndepositional erosion and gravitational slumping leads to the formation of travertine breccia.

We interpret the prominent crest as a fissure-ridge travertine (Bargar, 1978; Chafetz & Folk, 1984) formed on a fracture that can well be traced on aerial photographs for at least two kilometers. Quite similar fissure-ridges are known from the Yellowstone National Park (Bargar, 1978), several localities in New Mexico (Barker et al., 1996) and Pamukkale, Turkey (Altunel & Hancock, 1993). The bedded travertine forming the

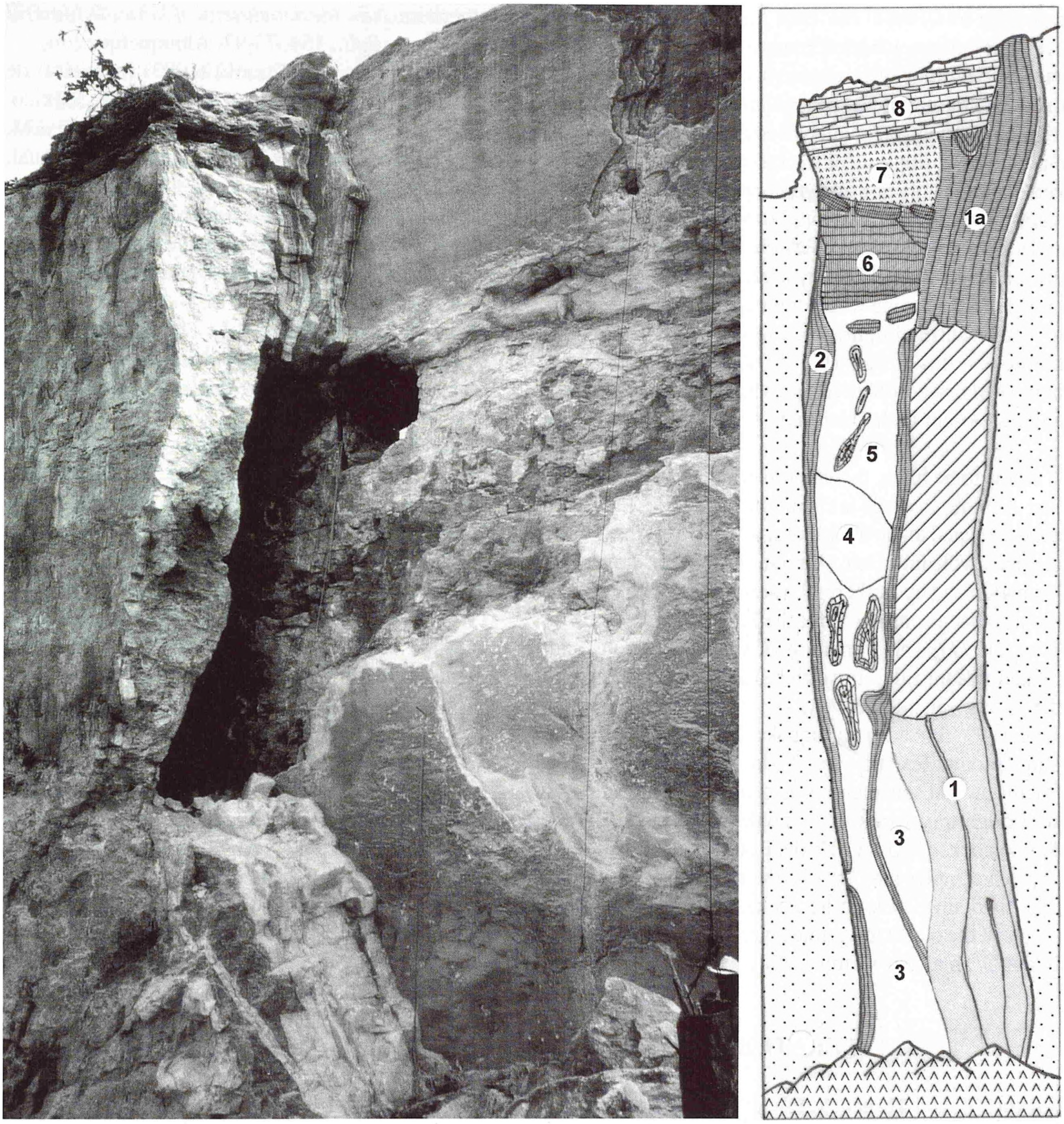

Fig. 6: - Exploitation of vertically banded light green travertine filling the crestal fissure of the main ridge. Left: oblique view of the fissure. Right: Sketch of the geological structure of the fissure fillings as seen in a perpendicular view. Heigth of the sketched area: ± 20 m.

1: dense, crystalline, green Onyx. Below the exploited sector relatively massiv, above it (1a) banded.:

2: Crusts of ray crystal travertine.

3: Fissure filling by brown to yellowish clayey material, locally showing fissures healed by younger crusts of crystal travertine (3a). Enclosed are columns and nodules of ray crystal travertine (stalagmites and/or stalagtites?).

4: Pocket, filled with olive-green, plastic clay.

5: Fissure filling by a breccia of calcareous rock fragments, containing fragments of hollow tubes, built by ray crystalline travertine.

6: Horizontally bedded travertine with reworked blocks near its surface.

7: Talus breccia with fragments of cretaceous limestone.

8: Caliche.

ridge dip away from the crest line on both sides and even cascade or waterfall travertine is developed. Several generations of travertine can be observed within the open pits cutting the central part of the ridge (Fig. 5/4). They reflect a chequered story of carbonate precipitation and subsequent fracturing (Fig.6). The oldest generation is a thick package of crystalline dense laminated travertine, more porous thin bedded tufa/travertine and interstratified breccia. A crestal fissure cross-cut this package and is filled by a vertically banded dense crystalline travertine with a light green color that is due to native sulfur impurities. Present mining strongly focuses on this variety (Fig. 6). A third generation of laminated fissure-fill travertine with beige to light brown color cross-cut both older units.

It seems to be likely that the travertine formation in the San Antonio Texcala area and in the whole Tehuacan zone is related to the hydrothermal activity of the Transmexican Volcanic Belt. A relation between travertine formation and hydrothermal waters of that volcanic belt has also been considered for the Puebla region by Erffa et al. (1977). The formation of fracture systems and related fissure-ridge travertine may well be related to the strong seismic activity, as recently shown by the June 1999 Tehuacan earthquake that also affected the San Antonio Texcala area. A similar relation between fracturing and seismicity is also considered for the fissure-ridge travertines of Pamukkale, Turkey (Altunel & Hancock, 1993). U/Th data of some San Antonio Texcala samples indicate that the travertines have been deposited since at least 52 ±5 ka. However, measurements of the oldest travertine layers did not deliver confident U/Th results so this is only a minimum age.

LITERATURE

Altunel, E. and **Hancock, P.L.** (1993) Active fissuring and faulting in Quaternary travertines at Pamukkale, western Turkey. *Z. Geomorph. N.F. Suppl.-Bd.*, **94**, 285-302, Berlin, Stuttgart.

Anonymous (1894) Mexican Onyx. *Manufacturer and builder*, **26(11)**, 254.

Barcena, M. (1874) Las rocas de Tecali (Puebla, Mex.). *La Naturaleza*, **1874**, 7-9, Mexico DF.

Barcena, M. (1876) The rocks known as Mexican onyx. *Proc. Acad. Nat. Sci. Philadelphia*, **1876**, 166-168, Philadelphia.

Bargar, K.E. (1978) Geology and thermal history of Mammoth Springs, Yellowstone National Park, Wyoming. *U.S. Geol. Surv. Bull.*, **1444**, 1-55, Washington.

Barker, J.M., Austin, G.S. and **Sivils, D.** (1996) Travertine in New Mexico - Commercial deposits and otherwise. *New Mexico Bureau of Mines & Mineral Resources, Bull.*, **154**, 73-92, Albuquerque..

Cardenas Vargas, J. (Coord.) (1993) Inventario de rocas dimensionables. Los marmoles de México. *Consejo de Recursos Minerales, Publ,.* **I-2e**, 1-124, Secretaria de Energía, Minas e Industriapara-estatal, Pachuca.

Chafetz, H.S., Akdim, B., Julia, R. and **Reid, A.** (1998) Mn- and Fe-rich black travertine shrubs: bacterially (and nanobacterially) induced precipitates. *J. sediment. Res.*, **68**, 404-412, Tulsa.

Chafetz, H.S. and **Folk, R.L.** (1984) Travertines: depositional morphology and the bacterially constructed constituents. *J. sediment. Petrol.*, **54**, 289-316, Tulsa.

Cserna, Z. de (1989) An outline of the geology of Mexico. In: **A.W. Bally** and **A.R. Palmer** (Eds.), *The Geology of North America - An Overview,* The Geology of North America, Vol. **A**, 233-264, Geological Society of America, Washington.

Erffa, A.v., Hilger, W., Knoblich, K. and **Weyl, R.** (1977) Geologie des Hochbeckens von Puebla-Tlaxcala und seiner Umgebung. *Das Mexiko-Projekt der Deutschen Forschungsgemeinschaft*, **11**, 1-130, Wiesbaden.

Folk, R.L., Chafetz, H.S. and **Tiezzi, P.A.** (1985) Bizarre forms of depositional and diagenetic calcite in hot-spring travertines, central Italy. *Soc. Econ. Paleont. Mineral. Spec. Publ.*, **36**, 349-369, Tulsa.

Ford, T.D. and Pedley, H.M. (1996) A review of tufa and travertine deposits of the world. *Earth-Sci. Rev.*, **41**, 117-175, Amsterdam.

Galván Villarreal, F. and **Martínez Vera, A.** (1995) Monografía geológico-minera del estado de Puebla. *Consejo de Recursos Minerales, Publ.* **M-16e**, 1-139, SECOFI, Pachuca.

Guo, L. and **Riding, R.** (1994) Origin and diagenesis of Quaternary travertine shrub fabrics, Rapolano Terme, central Italy. *Sedimentology*, **41**, 499-520, Oxford.

Guo, L. and **Riding, R.** (1998) Hot-spring travertine facies and sequences, Late Pleistocene, Rapolano Terme, Italy. *Sedimentology*, **45**, 163-180, Oxford.

Jones, B. and **Renaut, R.W.** (1996) Morphology and growth of aragonite crystals in hot-spring travertines at Lake Bogoria, Kenya Rift Valley. *Sedimentology*, **43**, 323-340, Oxford.

Kösler, H.J. (1991) *Lehrbuch der Mineralogie*. 5.Aufl., 1-844, Deutscher Verlag für Grundstoffindustrie, Leipzig.

Lawton, E.M. (1910) Genesis and classification of mexican onyx. *Mining and Scientific Press*, **1910**, 791-792, San Francisco.

Lopez Ramos, E. (1981) *Geología de México, Tomo II.* 1-446, Librerías CONACYT, México.

Michalzik, D. (1996) Lithofacies, diagenetic spectra and sedimentary cycles of Messinian (Late Miocene) evaporites in SE Spain. *Sediment. Geol.*, **106**, 203-222, Amsterdam.

Morán Zenteno, D. (1984) *Geología de la República Mexicana*. 1-88, Univ. Nac. Autón. México Inst. Nac. Estad. Geogr. Inform., Mexico.

Ortega-Gutiérrez, F., Mitre-Salazar, L.M., Roldán-Quintana, J., Sánchez-Rubio, G. and **de la Fuente, M.** (1990) *H-3: Middle America Trench-Oaxaca-Gulf of Mexico*. Geol. Soc. Amer. Centennial Conti-nent/Ocean Transect. #14.

Schreiber, B.C. and **Decima, A.** (1976) Sedimentary facies produced under evaporitic environments: a review. *Mem. Soc. Geol. Italiana*, **16**, 111-126, Rom.

Sedlock, R.L., Ortega-Gutiérrez, F. and **Speed, R.C.** (1993) Tectonostratigraphic terranes and tectonic evolution of Mexico. *Geol. Soc. Amer. Spec. Pap.*, **278**, 1-153, Washington.