Rev. Geol. Amér. Central, 16: 23-38, 1993

FLUID INCLUSION STUDIES OF EPITHERMAL GOLD-BEARING QUARTZ VEINS IN THE LA LIBERTAD DISTRICT, NICARAGUA

A. Morales[1], W. Vivallo[1] & M. Darce[2]
[1] Department of Geology, Stockholm University, S-10691 Stockholm, Sweden
[2] Instituto Nicaraguense de la Minería, Dirección General de Geología, Apartado Postal 195, Managua, Nicaragua

ABSTRACT: The La Libertad mining district in central Nicaragua, is an epithermal deposit of Au-bearing quartz veins hosted in Tertiary basic to intermediate volcanic rocks. Fluid inclusion studies in quartz from the epithermal veins show that the ore forming solution varies in temperature between 172 and 316°C with a mode around 230-240°C. The salinity of the solutions was in the range of 0.98-2.10 eq. wt.% NaCl. The original ore solution involved is defined as dominated by meteoric water and sodium chloride (NaCl), as the main component, no CO_2 was detected. The minimum depth of emplacement of the deposit was probably between 370-570 m. This gives an estimated erosion rate of 2.4-4.4 cm/1000 years and an estimated thermal gradient for the district of greater than 150°C/km. Due to the close relationship between the ore forming processes and volcanism in the district, the epithermal deposit at La Libertad appears to be the result of magmatic hydrothermal systems.

RESUMEN: El distrito minero de La Libertad es un yacimiento epitermal con vetas de cuarzo aurífero dentro de rocas volcánicas terciarias de composición básica hasta intermedia. Los análisis microtermométricos de las inclusiones fluidas dentro del cuarzo indican que la temperatura de las soluciones hidrotermales varía entre 172 y 316° C, con una promedio alrededor de los 230-240° C. La salinidad de las soluciones varía entre 0,98 y 2,10 %eq. peso NaCl. La solución metalífera consistió principalmente de aguas meteóricas con NaCl como sal principal; no se detectó CO_2. La profundidad del yacimiento era probablemente entre 370 y 570 m. La tasa de erosión estimada era de 2,4 - 4,4 cm/1000 años y el gradiente geotérmico era mayor de 150° C/km. Se supone que el yacimiento epitermal de La Libertad se originó por sistemas hidrotermales relacionados con la actividad volcánica.

INTRODUCTION

Gold is the most important mineral resource in Nicaragua, and the La Libertad gold deposit one of the oldest mine in the country. It is located in the central part of Nicaragua, 120 km east of Managua (Fig. 1). The district is about 20x5 km large and consists of a quartz-vein swarm hosting native gold and pyrite. The mined ores and reserves are together about 1.3 millions tons with an average gold content of 5 g/t (DARCE, 1989). La Libertad district is part of an ore province containing several gold and/or silver-bearing districts hosted in a belt of Cenozoic volcanic rocks extending from Guatemala to Costa Rica. These deposits are considered as typical epithermal ores (LEVY, 1970; SILLITOE, 1977).

Fluid inclusion studies in samples from the quartz veins were performed with the purpose of characterizing the ore forming fluids, in particular their trapping temperatures and salinities. Three samples from the Topacio district, a similar epithermal gold-district located about 80 km to the south-east from the La Libertad (Fig. 1), were also considered in this study for comparison.

REGIONAL AND LOCAL GEOLOGY OF THE LA LIBERTAD DISTRICT

The mining district La Libertad covers an area of about 100 km^2 and is centered on the village of La Libertad (Fig. 2). The regional and local geology of the area has been described by GARAYAR (1972), HODGSON (1980) and DARCE (1987a, 1989).

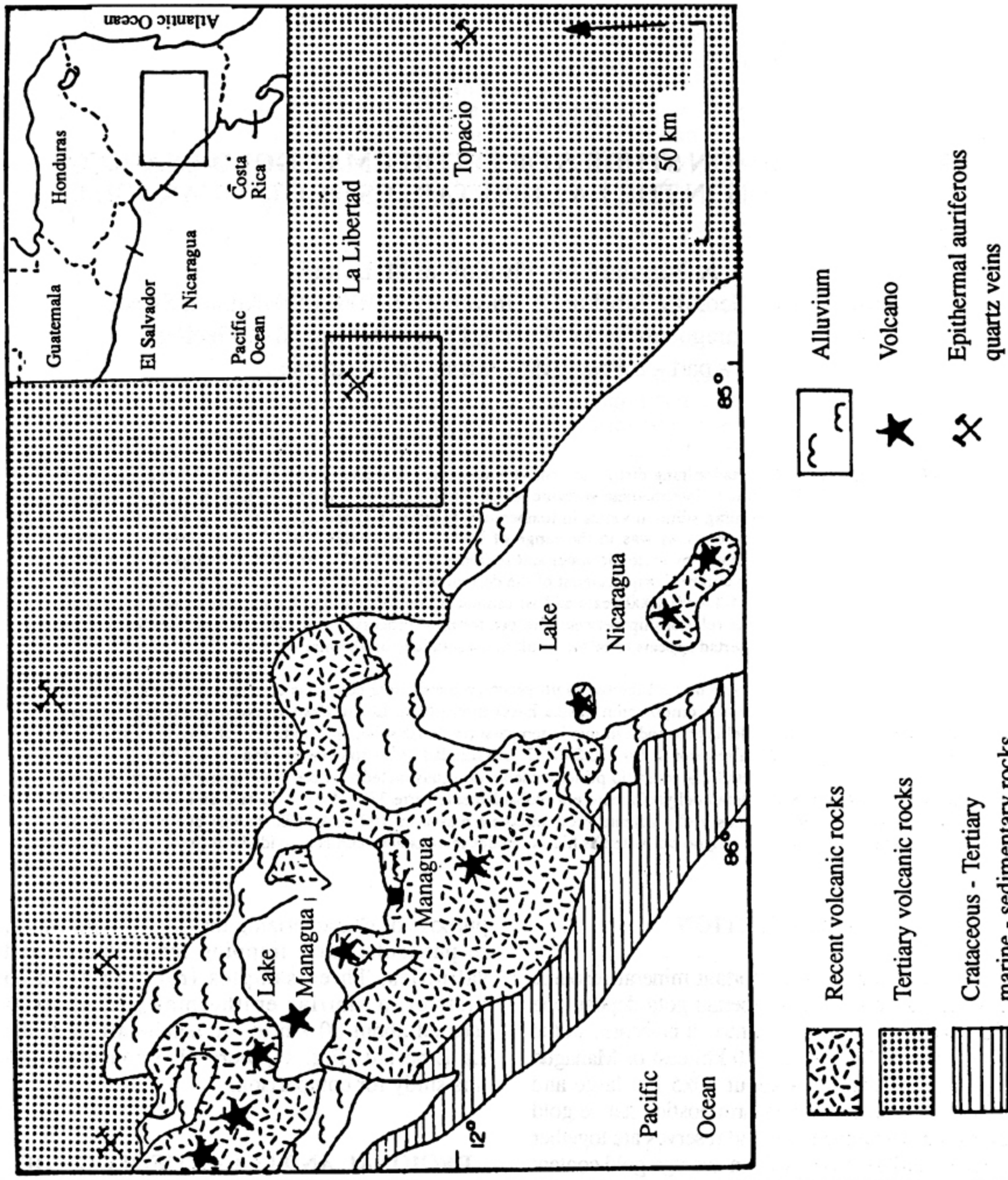

Fig. 1: Simplified geological map of a part of Central Nicaragua (modified from Mapa Geológico -Preliminar 1: 1000000, Nicaragua 1973) showing the location of the La Libertad (in the frame) and Topacio mining districts. Both gold district are hosted by Tertiary volcanic rocks.

The geology of the area is dominated by volcanic sequences of the Coyol (Miocene-Pliocene) and Matagalpa (Oligocene-Miocene) Groups. The relationships between the different stratigraphic units are presented in figure 3. The boundaries between the groups are indicated by unconformities. The general stratigraphy of the area shows that volcanic rocks, basic to acid in composition, are overlying sedimentary rocks from the El

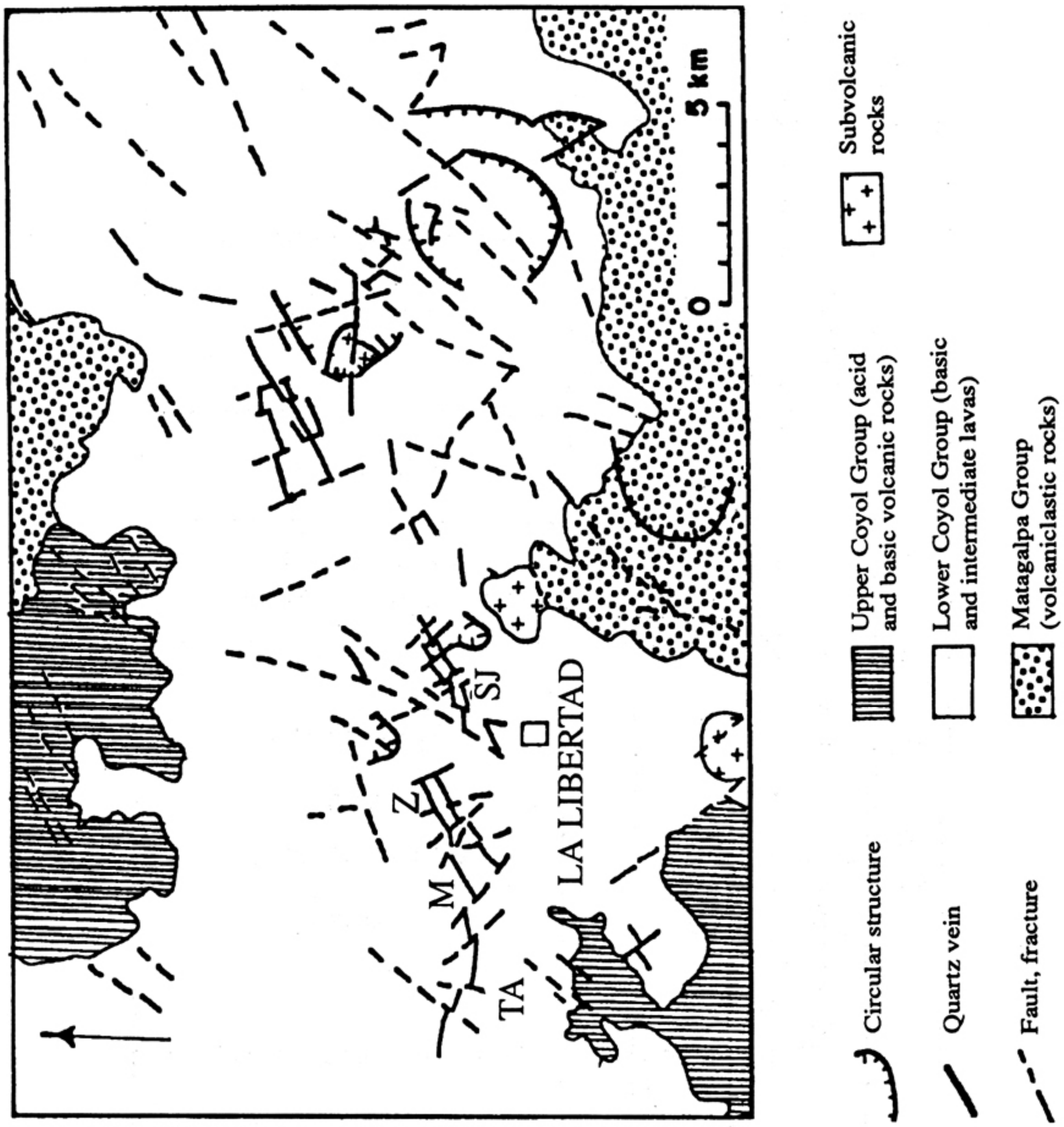

Fig. 2: Geological map of the La Libertad district (after Darce, 1989). M Mojon vein, SJ San Juan vein, TA Tres Amijos vein, Z Zopilote vein.

Caracol formation and the thickness of the volcanic sequence is about 1 km. Several small acid and basic subvolcanic intrusives, of approximately same age as the volcanics, are found in the area. They are distributed in a NE-SW trending zone parallel to the orientation of the fractures, faults and quartz veins in the district (Fig. 2).

The mining district La Libertad

The mining district is made up of a complex grid of subparallel quartz veins ranging from 0.5-20 m in width striking in a NE-SW direction, with dips of 65-85° to the NW-SE.The quartz veins are gold-bearing and hosted in basic to intermediate volcanic rocks belonging to the

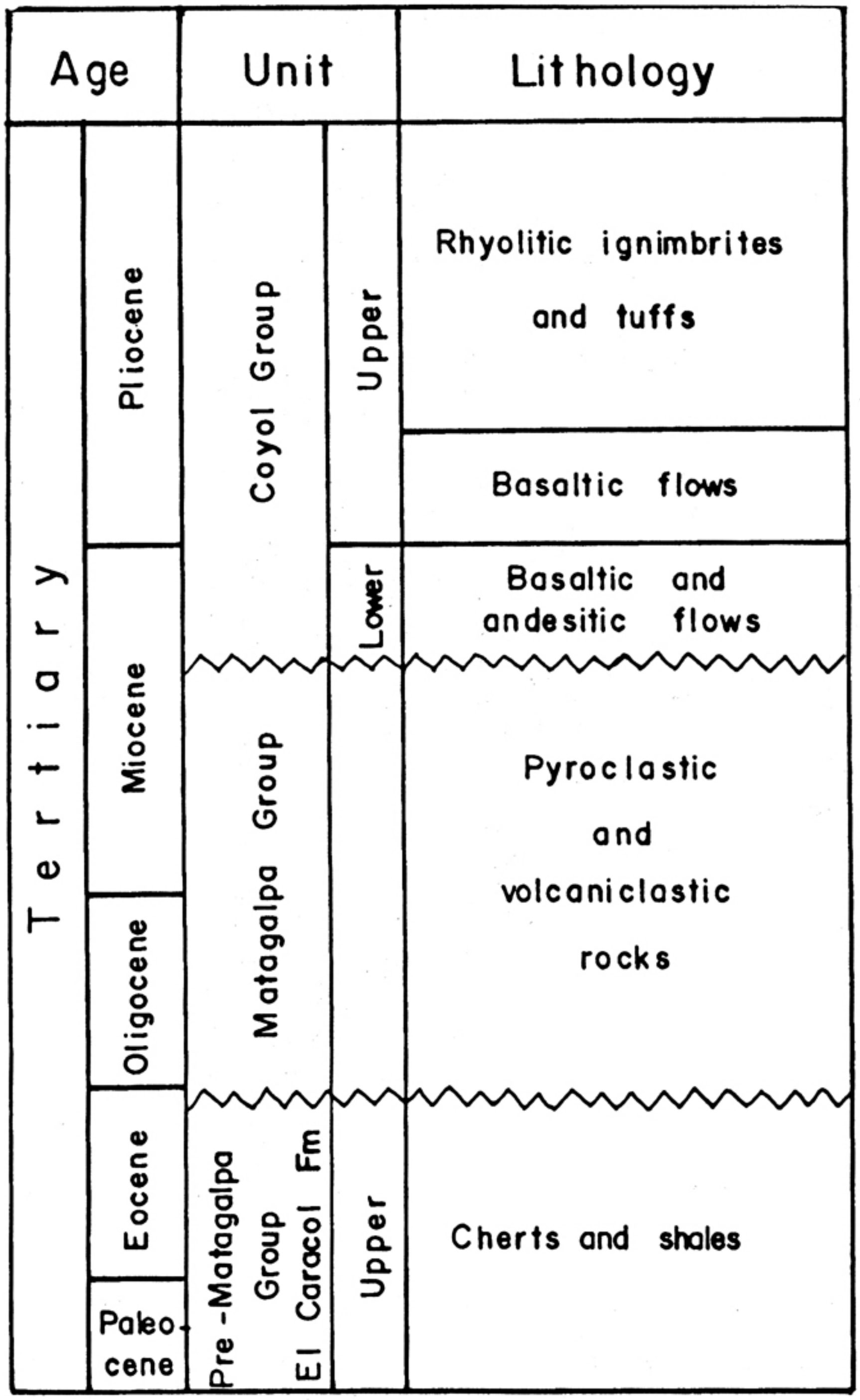

Fig. 3: Stratigraphic column of the stratified rocks in the la Libertad area (modified after Darce, 1987a)

Lower Coyol Group (Fig. 2). The mineralization consists of native gold and electrum associated with pyrite and different tellurides (HÅLENIUS, 1983) and occurs in fine grained, milky quartz, locally banded with saccaroidal textures or within geodes. Calcite and clay minerals are the other gangue minerals.

The gold content in the veins of La Libertad district ranges between 4 and 7 ppm. Based on geological considerations and comparison with other well preserved deposits in Nicaragua, DARCE (1987a) suggested that the richest part of the mineralization at La Libertad has been eroded away.

The district is affected by NW-SE transversal faults that have caused movements of blocks in different levels, transferring the veins in the district in a complicated pattern. Various observations show that these faults have been active before as well as after the formation of the quartz veins. The structural pattern of the area reveals the existence of circular structures of caldera type. LILLEQUIST & HOGDSON (1983) have suggested that such structures favored the formation of epithermal gold deposits.

Hydrothermal alteration

The quartz veins are surrounded by alteration aureoles of strongly altered volcanic rocks, of about a few decimeters up to several meters in width, and narrowing downwards like the quartz veins. At depth the aureoles consist of secondary minerals such as quartz, kaolinite, illite, K-feldspar and pyrite, whereas on the surface they are rich in kaolinite and K-feldspar is laking. Regionally, the volcanic rocks show a zoned alteration pattern with respect to the mining district and it reaches 8 km or more from the district. Based on the secondary mineral assemblages observed in the altered rocks, DARCE (1987b, 1989) has identified five different zones, with a grade and extent of the alteration increasing toward the mining district (Fig. 4). This zoned alteration pattern has been interpreted by DARCE (1987b, 1989) as representing an overprint on a regional low grade alteration of burial diagenetic type of the mordenite zeolite subfacies (with mineral assemblages stable at <150°C) by an alteration of geothermal field type with mineral assemblages suggesting higher temperatures (>240°C). This latter alteration type seems to be directly related to the deposition of the ore.

ANALYTICAL METHODS

The fluid inclusions were studied in 150-200 µm thick sections, polished on both sides and without covering glass in order to achieve minimal absorption and deviation of the light. The measurements were made using a heating stage of Chaixmeca construction (POTY et al., 1976). The stage was mounted on a modified Leitz Laborlux microscope, and a UMK 50 universal stage lens, fitted with a nominal magnification of 32x, was used during the measurements (LINDBLOM, 1982). Cooling was effected by introducing dry filtered air through a heat exchanger, filled with liquid nitrogen, into the stage. The cooling was kept to 10-20° C/minute to allow a proper observation of the temperature of nucleation (T_n) which occurs when the included phases become solid. Then, the cooling is stopped and the temperature allows to rise only by the effect of the ambient atmosphere. Then the inclusion begins to melt and the first melting of the solid phase is observed, this is the temperature of eutecticum (T_e), which often was difficult to detect. Finally, when the last ice phase melts, the temperature of melting (T_m) is noted. A "freezing point depression - eq.wt. % NaCl in solution curve" (POTTER et al., 1978), was used to determine the salt concentration in the fluid inclusion and hence of the ore solution.

Heating in order to measure the homogenization temperature (T_h) was performed by the resistance coil in the stage. The heating rate was kept to 2° C/minute, until 10°C below the expected T_h, where the rate was lowered to 0.5-1.0° C/minute. The homogenization temperature and the melting temperature were determined on almost every inclusion. The temperature of eutecticum was measured on relatively few inclusions due to the difficulties on observing the criteria to establish this temperature.

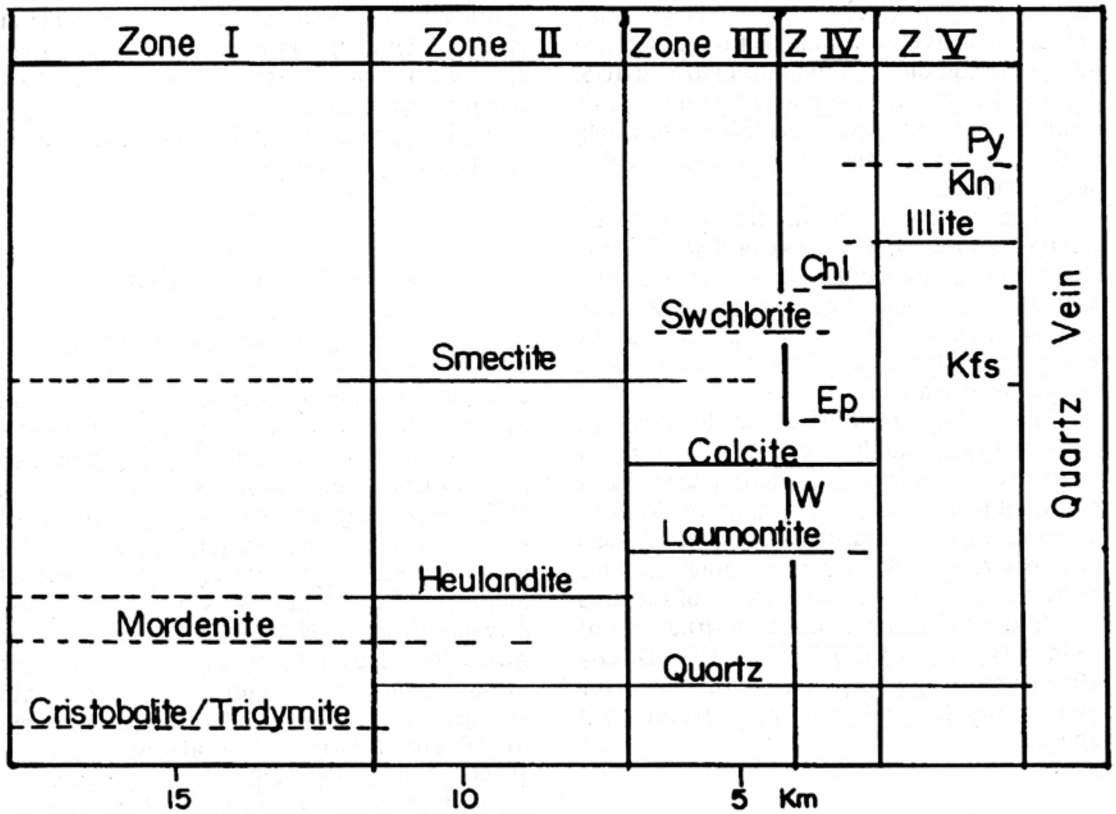

Fig. 4: Regional distribution of secondary minerals in outcrop samples and drillcores from the La Libertad region (After Darce, 1989). The km scale is only schematic, kaolinite and K-feldspar are restricted to the vein aureoles. Ch chlorite, Ep epidote, Kfs K-feldspar, Kln kaolinite, Py pyrite, sw swelling, W wairakite, Z zone.

SAMPLE DESCRIPTION

Quartz veins of the La Libertad and Topacio gold districts were sampled both in outcrops and drillcores, and their descriptions are summarized in table 1. They include small veins of only a few centimeters thick with transparent, coarse-grained and well crystallized quartz, and thicker veins of milky, fine- grained quartz which often display banding, colloform texture and in some cases brecciation. The study was focused in grain quartz and 5-45 µm large inclusions were found mainly in transparent and well crystallized quartz.

Samples San Juan 451 and Topacio 631 are the only mineralized with sulfide, in this case pyrite. And the quartz from samples San Juan 451-1 and 451-3 display growth zonations.

Primary inclusions

Most of the measured fluid inclusions are two-phase (liquid- vapor) irregularly to regularly shaped, and size ranging between 5-45 m, but commonly smaller than 30 µm. The vapor/volume ratio varies between 5 and 30 % of the total volume, and only the sample Mojón 652 and those from Topacio vein display larger variations (10-70 % of the total volume). One phase primary fluid inclusions (samples Tres Amigos 654-1 and Topacio 1-2) are characterized by negative crystal shape.

Secondary or pseudosecondary fluid inclusions

Two phase inclusions of probable secondary or pseudosecondary character were

Table 1

Description of the samples from the quartz veins in the La Libertad and Topacio district, Nicaragua.

Sample	Depth (m)	Vein texture/structure	Type of fluid inclusion
San Juan vein			
624-1	Surface	Fine-grained, vuggy quartz with colloform texture	Primary, two phase (liquid-vapor), irregular shapes, 10-45 µm. Vapor volume 5-30% of the total volume
624-2	Surface	Fine-grained, vuggy quartz with colloform texture	Primary, tabular shapes, 10-25 µm, vapor volume 2-20% of the total volume
451-1	133 m	1-2 cm thick vein, well crystalized fine-grained quartz, growth zonation in the crystal, pyrite is present	Primary, two phase, irregular shapes, 5-19 µm, vapor volume 5-10% of the total volume
451-2	133 m	1-2 cm thick vein, well crystalized fine-grained quartz, without growth zonation	Primary, two phase, regular to semi-regular shapes, 5-2- µm, vapor volume 5-10% of the total volume
451-3	133 m	1-2 cm thick vein, well crystallized fine-grained quartz, without growth zonation	Primary, two pahse, irregular shapes, 5-20 µm, vapor volume 5-10% of the total volume
Zopllote vein 625	Surface	Very well crystallized quartz, 1-10 mm in size growing outwards at right angles from the wall rock	Primary, two phase, irregular to regular shapes, 5-20 µm, vapor volume 5-15% of the total volume, occuring in cluster in the central part of the crystal
656	Surface	Milky, vuggy quartz with banding, very fine-grained	a) Primary, two phase, regular to irregular shapes, 5-30 µm, vapor volume 5-20% of the total volume b) Secondary, one phase (liquid), 10-20 µm, aligned close to each other (healed fracture?)
Tres Amigos vein 654-1	Surface	Milky, fine-grained quartz, with colloform, texture. Brecciated with three different quartz generations	a) Primary, one phase, regular to semi-regular shapes, 5-20 µm b) Secondary or pseudosecondary, two phase inclusions, located close to fractures, vapor volume 5-10% of the total volume
654-2	Surface	Milky, fine-grained quartz, with colloform texture. Brecciated with three different quartz generations	Primary, two phase, regular shapes, 4-6 µm, vapor volume 10-30% of the total volume
Mojón vein 652	Surface	Brecciated, milky quartz and volcanics fragments in a matrix of fine-grained milky quartz. The quartz fragments are brecciated	Primary, irregular to regular shapes, 5-20 µm, vapor volume 10-50% of the total volume
Azul vein	71 m	1-2 cm thick vein of large and well crystallized quartz growing at right angles from the wall rock	Pseudosecondary?, two phase inclusions, regular to semi-regular shapes, aligned at right angle to growth surfaces of the crystals, 5-20 µm, vapor volume 5-10% of the total volume
Topacio vein 1-2	Surface	Fractured milky quartz, with crosscutting quartz veinlets of well crystallyzed quartz	a) Primary, one phase inclusions, regular shapes, 5-10 µm b) Primary, two phase, regular to semi-regular shapes, 5-15 µm, vapor volume 10-20% of the total volume

Table 1. Cont.

Sample	Depth (m)	Vein texture/structure	Type of fluid inclusion
631-1	60 m	15 cm wide quartz vein, fine-grained and well crystallized, dissemination of pyrite	Secondary or pseudosecondary two phase incluions, 6-13 μm, flat to tabular, vapor volume 5-10% of the total volume. They occur at stright planes paralell with the grain borders, and with fractures normal to the grain borders
631-2	60 m	15 cm wide quartz vein, fine-grained and well crystallized, dissemination of pyrite.	a) Primary two phase inclusions, semi-regular shapes, 5-15 μm, ramdomly distribution, vapor volume 5-10% of the total volume b) Primary two phase inclusions, irregular shapes, 4-22 μm, vapor volume 20-70% of the total volume

observed only in samples Azul vein and Topacio vein 631-1. The one phase inclusions in sample Zopilote 656 are aligned close to each other, probably representing a healed feature, and they are interpreted as of secondary origin.

RESULTS

The results of microthermometry on quartz fluid inclusions are summarized in table 2. A total of 116 inclusions were measured and the temperatures of homogenization (T_h) range between 169 and 372° C. In the La Libertad district the fluid inclusions can be separated in three different groups (Fig. 5), a low temperature group with T_h values lower than 200° C, a subordinate group of high temperature inclusions (>280° C), whereas most of the fluid inclusions are grouped in the interval between 210-280° C with a peak around the interval 230-240° C. The distribution of temperatures for the samples from the Topacio district show a larger spreading. The inclusions are commonly liquid-dominated but the overall range of vapor volume varies as much as 5-70 % of the total volume (especially in samples from the Topacio veins) suggesting that these samples were probably subjected either to boiling, necking down or growth zonation during the formation of the mineral.

The T_m values (Fig. 5) range between -0.5 and -0.7° C, indicative of low salinities (commonly <2 wt.% NaCl equivalent). No differences in T_h or T_m were detected between secondary and primary inclusions. A few T_e values ranging between -20 and -40.5° C were obtained proving furthermore the presence of mainly NaCl, with probably lesser amounts of $CaCl_2$ in the solutions. CO_2 was not detected in the samples.

San Juan vein 451 is characterized by higher T_h and slightly lower T_m values than San Juan vein (Fig. 6). These differences probably reflect the structure of the vein which consists of several bands of quartz with colloform texture and the different temperature ranges may represent different quartz generations; or alternatively, the higher temperatures represent a more deeper part of the vein. The large spread of the T_h values in the San Juan vein 451 (Fig. 6) is also consistent with the zoned structure of the quartz crystals in this vein, which display a distinct thermal zoning with decreasing T_h towards the crystal rims. The colloform quartz of Zopilote 656 displays higher average T_h values than the well crystallized quartz of Zopilote vein 625 (Fig. 6). The large spread of T_h values observed in the Tres Amigos vein (Fig 6), agrees well with the brecciated appearance of the vein, and probably reflects several generations of quartz, formed at different temperatures and time. The same seems to be the case in the Moion 652

Table 2

Results for T_h and T_m determination in fluid inclusions from quartz veins in the La Libertad and Topacio districts, Nicaragua

Sample	T_h average (°C)	T_h range (°C)	T_m average (°C)	T_m range (°C)
San Juan vein				
624-1	227	224 - 235	- 1.2	-0.6 - -1.8
624-2	250	234 - 272	- 1.0	-0.7 - -1.8
451-1	292	242 - 316	- 0.8	-0.6 - -1.2
451-2	235	213 - 260	- 0.8	-0.6 - -1.1
451-3	263	241 - 288	- 0.9	-0.5 - -1.8
Zopilote vein				
625	192	178 - 212	- 1.1	-0.5 - -2.2
656	229	172 - 266	- 0.6	-0.5 - -0.7
Tres Amigos vein				
654-1	215	169 - 238	- 0.7	-0.5 - -1.6
654-2	195	177 - 220	- 0.9	-0.5 - -1.4
Mojón vein				
652-1	240	194 - 270	- 0.9	-0.7 - -1.4
Azul vein				
	199	179 - 227	- 0.8	-0.4 - -1.1
Topacio vein				
1-2	222	208 - 230	- 1.0	-0.7 - -1.4
631-1	268	104 - 275	- 1.3	-0.4 - -1.7
631-2	315	171 - 372	- 0.9	-0.4 - -1.2

(Fig. 6). The Azul and Zopilote 625 veins display the lowest T_h values, whereas the highest T_h values in La Libertad district were measured in the lower part of the San Juan 451 vein, 316° C (Table 2).

As a comparison, the Topacio district displays the highest T_h values between the two districts, in excess of 372° C in its lower parts (Fig. 7). The vapor volumes measured range between 5 and 70 % of the total volume and the homogenization temperature between 179 and 372° C. The salinity values are similar to those for the La Libertad district.

The T_m-T_h diagram (Fig. 8) shows, for the Zopilote, San Juan and Topacio veins, a distinct negative correlation between T_m and T_h, where decreasing temperature is followed by an increasing salinity of the solutions. Furthermore, this figure discriminate between several different types of solutions, each one characterized by small differences in salinities and larger differences in temperatures. Pyrite, (gold ?), was only observed in the two depth samples of San Juan 451 and Topacio 631 veins, associated with quartz and characterized by high T_h values.

DISCUSSION

It has been stated above that the ore forming solutions in the mining district La Libertad and in the Topacio vein are characterized by T_h ranging between 169 and 372° C (Table 2) and T_m values in the range -0.5 to -1.7° C, suggesting salinities between 0.98 and 2.15 eq. wt.% NaCl with an average of 1.43 eq. wt.% NaCl. These features are consistent with the temperatures and salinities commonly described for precious metal bearing epithermal deposits and active geothermal fields hosted in similar volcanic environments (HEDENQUIST & HENLEY, 1985; HEALD et al., 1987; KLARKE & TITLEY, 1988). The low salinity of the solutions suggests that the main component was meteoric water (ELLIS, 1967; SAWKINS et al., 1979; SPOONER, 1981; HEALD et al., 1987). and the composition dominated by chloride complexes.

CO_2 was not observed in the fluid inclusions of the La Libertad district. However, the observed variation of the T_m values at La Libertad, could be also consistent with the presence of small amount of not detected dissolved CO_2 in the inclusions (cf. KLARKE & TITLEY, 1988). Dissolved CO_2 may make a

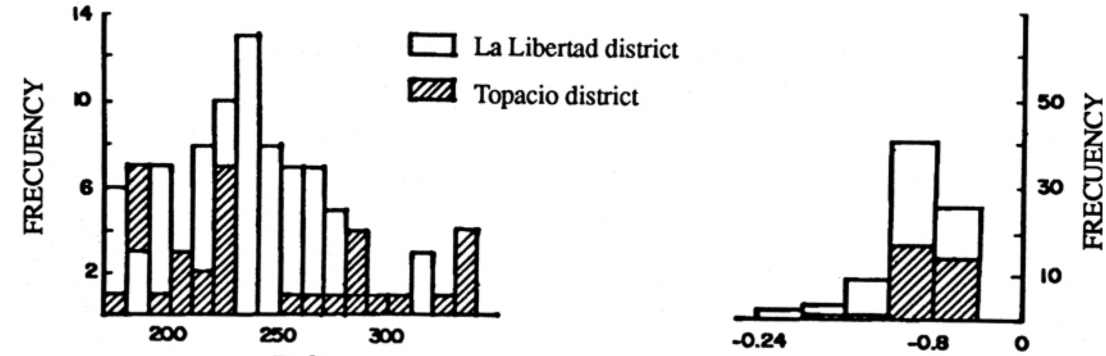

Fig. 5: Homogenization (T_h) and melting (T_m) temperatures for samples from the La Libertad and Topacio gold districts.

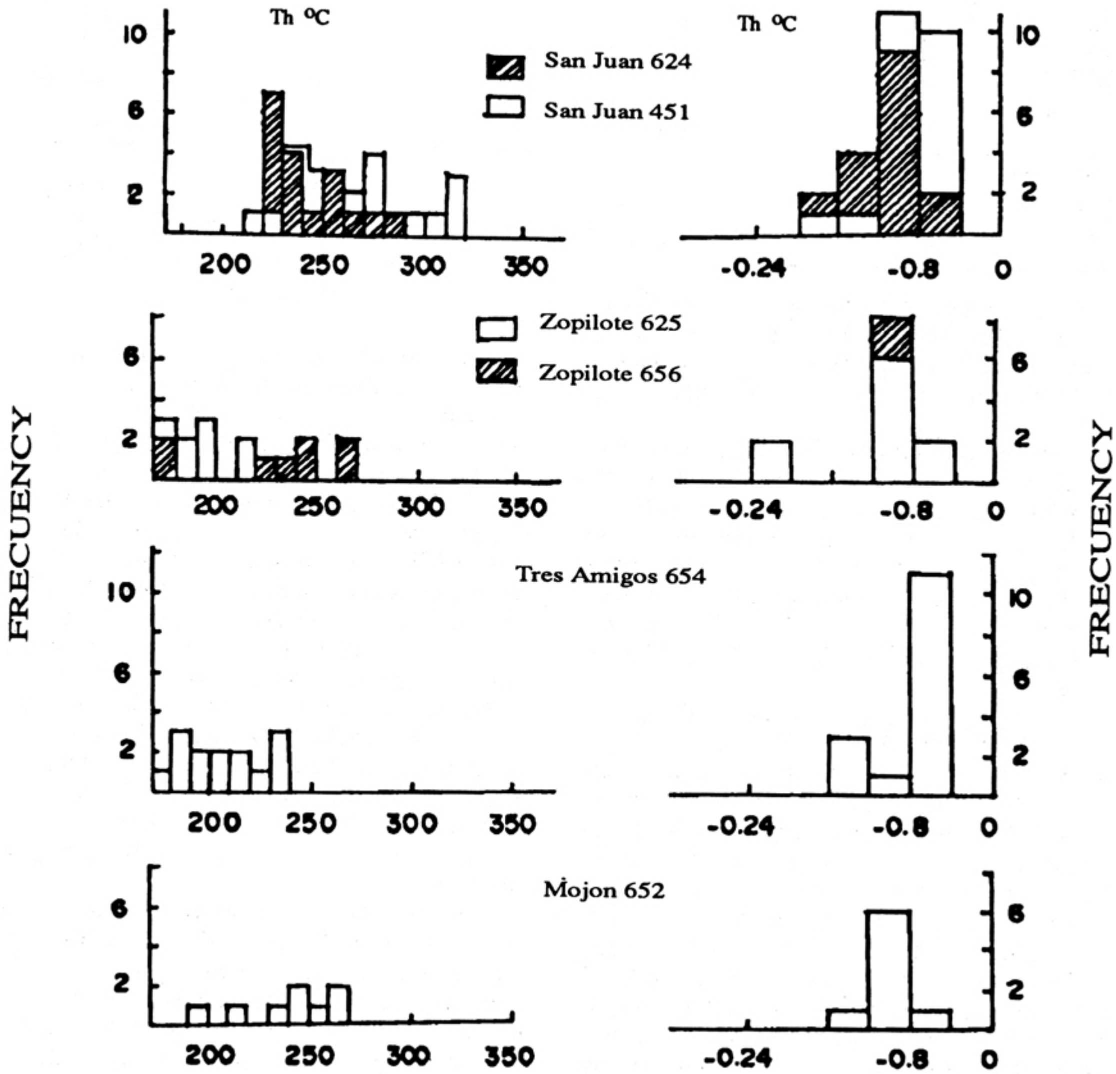

Fig.6: Homogenization (T_h) and melting (T_m) temperatures for individual veins from the La Libertad district.

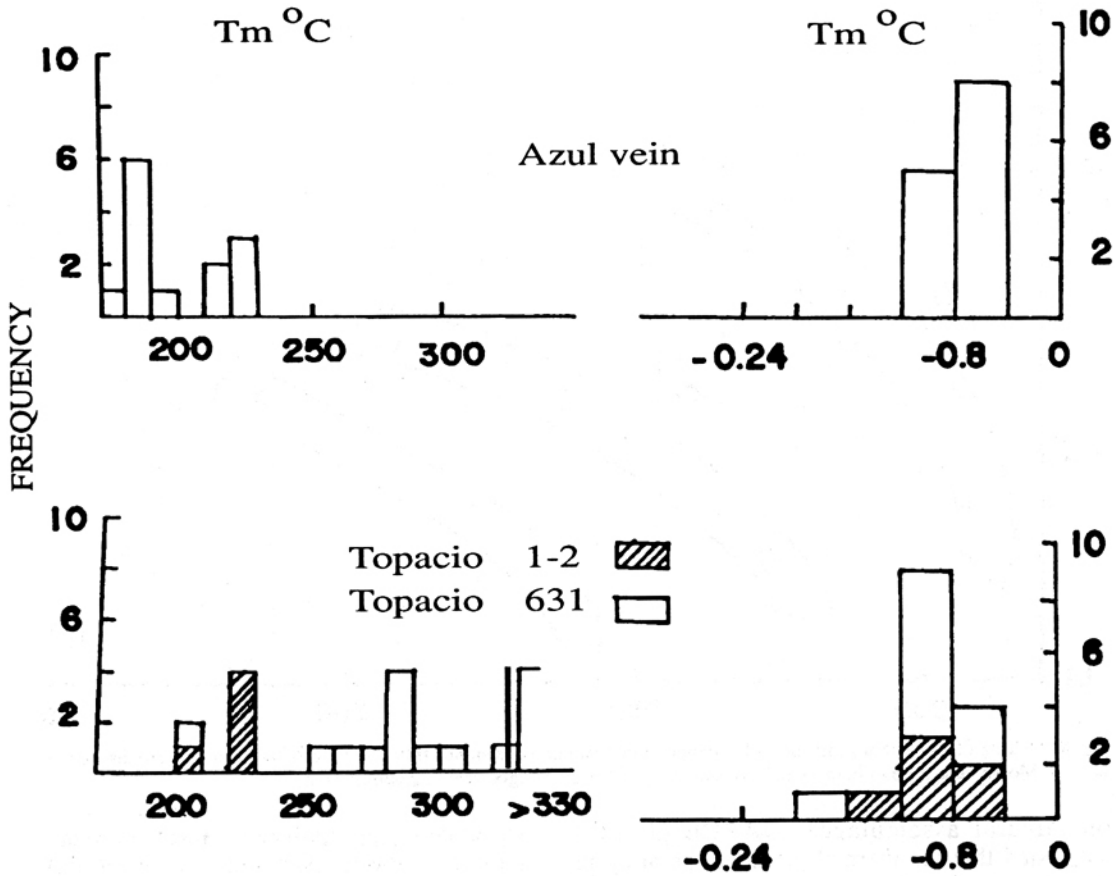

Fig. 7: Homogenization (T_h) and melting (T_m) temperatures for the Topacio and Azul veins in the Topacio district.

relatively large contribution to the depression of the T_m in dilute fluids, suggesting apparent salinities much higher than are actually present (HEDENQUIST & HENLEY, 1985). The observed T_m variations could be also a result of the multistage evolution of the veins as evidenced by their banded and brecciated structures. These structures suggest episodic introduction of fluids over the life of the hydrothermal system, each one with a possible distinct initial composition. The apparent absence or low content of CO_2 is also a common feature of many volcanic hosted epithermal deposits.

Thermal gradient and evidence of boiling

The T_h-T_m diagram (Fig 8), based on average values, indicates an evolving trend of the ore-bearing fluids from a solution of high temperature and low salinities at depth and lower temperature and higher salinities in the uppermost part of the deposits. Based on the values from the San Juan and Zopilote veins, a thermal gradient grater than 150° C/km may be estimated for the district. This agree with known values observed in areas of recent volcanism or active geothermal fields (HENLEY, 1985: SPOONER, 1981). Based

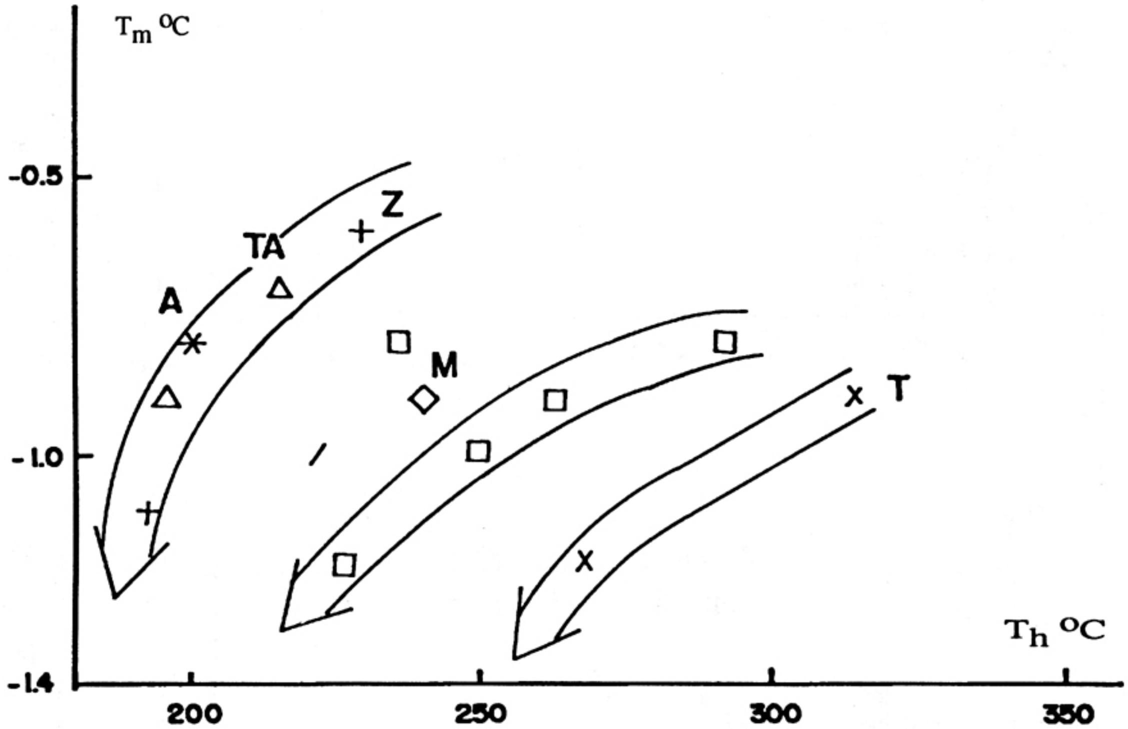

Fig. 8: Melting (T_m) - Homogenization (T_h) temperature diagram for samples from the La Libertad and Topacio districts. A Azul vein, M Mojon vein, SJ San Juan Vein, T Topacio vein, TA Tres Amigos vein, Z Zopilote vein.

on mineral assemblages, DARCE (1987b) suggested that the thermal gradient operating in La Libertad district during the ore forming stage was in excess 150° C/km. The results presented in figure 8 suggest that temperature changes could play an important roll in the ore deposition.

Based on the observed textures and structures of the Au- bearing veins in the La Libertad district, the veins may be classified in two large groups: a) veins consisting of large and well-crystallized quartz, normally without thermal zoning; and b) veins with very fine-grained milky quartz and colloform textures, and sometimes brecciated. The first group commonly displays relatively low T_h and when thermal zoning is present the T_h decreases successively from the central part of the crystal to the rim. This is consistent with a slow crystal growth from the hydrothermal solution. The fine-grained milky quartz with colloform texture shows the highest measured T_h values but also a relatively large spread. This kind of texture suggests that the quartz probably was suddenly precipitated from a solution supersaturated with respect to silica (SPOONER, 1981; FOURNIER, 1985). The T_h variations suggest furthermore that these veins were formed by several pulses of solutions at different temperatures.

Brecciation in the veins can be related to synvolcanic faulting or the hydrothermal activity itself, and even to the interaction of both processes. Even though, no definitive evidences of boiling were observed, there are several observations (e.g. San Juan 451, Topacio 631 and Mojon 652 veins) suggesting that this was the case, e.g. the wide range of gas infilling in several samples, fluid inclusions with an important gas phase (about 70 vol.%), and large variations in T_h within quartz grains from the same sample, but in this case growth zonation can not be ruled out.

The evolutive trend shown in figure 8 is also consistent with a solution that cools and boils towards the uppermost part of the vein (ROEDDER, 1984).

The higher T_h values obtained for San Juan 451 and Topacio 631 veins, together with the associated sulphide minerals, suggests a deposition of these minerals at a higher temperature interval than prevalent in the other samples.

Primary and secondary fluid inclusions

No large differences in the T_h and T_m values are observed between primary and secondary fluid inclusions. Heating of inclusions to homogenization is assumed to indicate the original temperature of formation in the case of primary and pseudosecondary inclusions since no pressure correction is necessary for the estimated depth of formation. Secondary fluid inclusions are generally explained as formed during metamorphic events or by tectonic deformation (ROEDDER, 1977; BODNAR et al, 1985). The metamorphism in the Libertad area can not explain the formation of secondary inclusions. The fact that many of the veins are related to fractures or faults, and being cut by faults, suggests that the formation of secondary fluid inclusions may be related to synvolcanic tectonism that was active before, during and after the ore deposition and the hydrothermal activity itself. An origin of the secondary inclusion by synvolcanic faulting explain its similarity with the primary fluid inclusions and suggest that they closely represent the primary environment of quartz formation. This suggest that a clear determination of the origin of the fluid inclusions present in this study becomes rather ambiguous due to the difficulty to establish the difference between the initial hydrothermal solution and the later ones that formed the veins.

Depth of emplacement of the ores

Based on samples from Mojón 652 and San Juan 451 veins, and assuming that the fluids were close to the H_2O liquid-vapor phase boundary during the deposition of the veins a minimal depth of emplacement between 370-570 m can be determined (HAAS, 1971). Based on these values and using a most probably younger estimated age for the mineralization of about 10 Ma (cf. DARCE, 1989), in comparison of the age of the wallrock 13-15 Ma (PARSONS CORP., 1972), the estimated rate of erosion will be in the order of 2.4 to 4.4 cm/1000 years. This figure agrees with other estimations for deposits formed in connection with Tertiary volcanism (CASADEVALL & OHMOTO, 1977; KAMILLI & OHMOTO, 1977; HÅLENIUS, 1985).

CONCLUSIONS

Fluid inclusion studies indicate that the ore forming solutions that controlled the deposition of the gold-bearing quartz veins in La Libertad district varied in temperature between 172-316° C, with a mode around 220-240° C. The salinity values obtained were in the range of 0.98-2.10 eq.wt.% NaCl with a mean of 1.43. The solutions involved are defined as dominated by meteoric water and sodium chloride (NaCl) as the main component, CO_2 was not detected.

Two types of epithermal quartz veins are present in the district: a) quartz veins with large and well crystallized quartz, commonly without thermal zoning, probably formed by a slowly growth from the hydrothermal solution and b) veins consisting of fine-grained milky quartz with colloform textures and sometimes brecciated, which suggests rapid deposition from a hydrothermal solution saturated with respect to silica and a complex evolution with participation of a multitude of hydrothermal fluids. The first group displays lower T_h values than the second group. This means that the thermal history of the veins was controlled probably by several different pulses with solutions at different temperatures and varying degrees of saturation with respect to silica during the depositional events.

A thermal gradient greater than 150° C/km is estimated for the district during ore deposition. Based on samples with evidences of boiling during ore deposition, it is suggested that the veins were formed at minimum depths ranging between 370 and 570 m, implying subsequently that the area was affected by erosion at a rate of 2.4-4.4 cm/1000 years, which is normal for similar volcanic sequences bearing epithermal deposits.

The evolutive trend shown in figure 8 supports the normal path of a solution that cools and boils towards the uppermost part of its vertical displacement as in the case of San Juan veins. The interpretation of the trends shown in figure 8 is supported by the textures of the two dominating quartz types as a succession from colloform, fine-grained quartz (higher temperature and lower salinities) to more well-crystallized quartz grains (lower temperatures and higher salinities). The textures present and the mineral association involved indicate that the deposition of sulphides (and probably of precious metals too) seems to be more favorable at higher temperatures than those proposed for the main episode of quartz deposition (230-240° C).

ACKNOWLEDGEMENTS;

This work was improved by the criticism of Curt Broman, Sten Lidblom, and Krister Sundblad. The advisement of C. Broman and S. Lindblom at the Fluid Inclusion Laboratory (University of Stockholm), and the cooperation of K. Sundblad with samples from the Topacio district are acknowledged. Financial support to M. Darce and W. Vivallo was provided by SAREC (Swedish Agency for Research Cooperation with Developing Countries).

REFERENCES

BODNAR, R.J., REYNOLDS, T.J. & KUEHN, C.A., 1985: Fluid inclusion systematic in epithermal systems. - Rev. Economic Geol., *2:* 73-97.

CASADEVALL, T. & OHMOTO, H., 1977: Sunnyside, Eureka mining district, San Juan County, Colorado: geochemistry of gold and base metal ore deposition in a volcanic environment. - Economic Geol., *72:* 1285-1320.

DARCE, M, 1987a: Geología del distrito minero de La Libertad, Nicaragua. - Rev. Geol. América Central, *7:* 65-82.

——— 1987b: Mineralogical alteration patterns in the volcanic rocks of La Libertad mining district and its surroundings, Nicargua - a progress report. - Unpublished INMINE/SAREC/SGAB, report SGAB, Luleå (Sweden), 60 pp.

——— 1989: Mineralogical alteration patterns, chemical mobility and origin of the La Libertad gold deposit, Nicaragua. - PhD thesis, Geological Institute, University of Stockholm, 103 pp.

ELLIS, A.J., 1967: The chemistry of some explored geothermal systems. *In:* BARNES, H.L. (ed.): Geochemnistry of hydrothermal ore deposits: 465-514; Rinehart & Wilson, New York.

FOURNIER, R.O., 1985: The behavior of silica in hydrothermal solutions. - Rev. Economic Geol., *2:* 45-62.

GARAYAR, J., 1972: Geología y depósitos minerales de la región de Chontales y Boaco. - Unpublished report, Informe No. 11, Catastro y Recursos Naturales, División Geología, Managua, Nicaragua, 30 pp.

HAAS, J.L.Jr., 1971: The effect of salinity on the maximum thermal gradient of a hydrothermal system at hydrostatic pressure. - Economic Geol., *66:* 940-946.

HEALD, P. FOLEY, N.K. & HAYBA, D.O., 1987: Comparative anatomy of volcanic-hosted epithermal deposits: acid-sulfate and adularia-sericite types. - Economic Geol., *82:* 1-26.

HEDENQUIST, J.W. & HENLEY, R.W., 1985: The importance of CO_2 on freezing point measurements of fluid inclusions: evidence from active geothermal systems and implication for epithermal ore deposition. - Economic Geol., *80:* 1379-1406.

HENLEY, R.W., 1985: The geothermal framework of epithermal deposits. - Rev. Economic Geol., *2:* 1-24.

HODGSON, G., 1980: Estudio geológico de la mina La Libertad. - Unpublished report, Instituto Nicaraguense de la Minería, 20 pp.

HÅLENIUS, U., 1983: A mineralogical investigation of the gold bearing vein type deposits at La Libertad, El Limón, and Rincón García, Nicaragua. - Unpublished INMINE/SAREC/SGAB, report SGAB, Luleå (Sweden), 15 pp.

——— 1985: Fluid inclusion microthermometry on quartz from the Panteón vein, El Limón area, Nicaragua. -

Unpublished INMINE/SAREC/SGAB, report SGAB, Luleå (Sweden), 29 pp.

KAMILLI, R.J. & OHMOTO, H., 1977: Paragenesis, zoning, fluid inclusion and isotopic studies of Finlandia vein, Colqui district, central Peru. - Economic Geol., *72:* 950-982.

KLARKE, M, & TITLEY, S.R., 1988: Hydrothermal evolution in the formation of silver-gold veins in the Toyalita Mine, San Dimas district, Mexico. - Economic Geol., *83:* 1830-1840.

LEVY, E., 1970: La metalogénesis en América Central. - Publ. Geol. No.3, Inst. Centroamericano de Investigación y Tecnología Industrial (ICAITI), Guatemala: 17-76.

LINDBLOM, S., 1982: Fluid inclusion studies of the Laisvall sandstone lead-zinc deposit, Sweden. - PhD thesis, Geological Institute, University of Stockholm, 171 pp.

LILJEQUIST, R. & HODGSON, G., 1983: Structures and rock formations related to precious metal vein deposits in Nicaragua. - Unpublished INMINE/ SAREC/ SGAB, report SGAB, Luleå (Sweden), 63 pp.

PARSONS CORP, 1972: The geology of western Nicaragua. - Nicaragua Tax Improvement and Natural Resources Inventory Project, Final Technical Rep., vol IV, 220 pp.

POTTER II, R.W., CLYNNE, M.A. & BROWN, D.L., 1978: Freezing point depression of aqueous sodium chloride solutions. - Economic Geol., *73:* 284-285.

POTY, B., LEROY, J. & JACHIMOWICZ, L., 1976: Un nouvel appareil pour la mésure des temperatures sous le microscope: l'installation de microthermometrie Chaixmeca. - Bull. Soc. Française Minéralogie Cristallographie, *99:* 182-186.

ROEDDER, E., 1977: Fluid inclusions as tools in mineral exploration. - Economic Geol., *72:* 503-528.

——— 1984: Fluid inclusions. - Rev. Mineralogy, Mineral. Soc. Amer., 12, 644 pp.

SAWKINS, F.J. O'NEIL, J.R. & THOMPSON, J.M., 1979: Fluid inclusion and geochemical studies of vein gold deposits, Baguio district, Philippines. - Economic Geol., *74:* 1420-1434.

SILLITOE, R.H. 1977: Metallic mineralization affiliated to subaerial volcanism: a review. –Geol. Soc. London Spec. Publ., *7:* 99-116.

SPOONER, E.T.C., 1981: Fluid inclusion studies of hydrothermal ore deposits. - Short Course Handbook, Mineralog. Ass. Canada, *6:* 213-216.