Analysis of ore bearing volcanic arc magmatites in East Cuba

Érchordozó magmatitok vulkáni szigetív eredetének elemzése Kelet Kubában

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Abstract – A Hungarian mapping and mineral prospecting geological expedition to Cuba in the area of northeastern Oriente (1984-1988) gave a new and more detailed view of the geology of the Holguín area. The Cuban part of the Bahama Platform that is the southern extension of the North American plate – exposed in Oriente – is the basement of the imbricated-melange nappe system that is thrust over it from SSW and consists of Cretaceous ophiolites and remnants of volcanic island-arcs. The imbricated melange system thrust over the margin of the North American continent that belongs to the Bahama Platform. It consists of Cretaceous ophiolites and remnants of volcanic island arcs. Most of the polimetallic injections containing precious metals are associated with basic neutral and acid igneous rocks that are in paraautochtonous position embedded in the inter imbrication spaces of the melange. These inter imbrication spaces as parent rocks were contactised by the intrusives. Using modal and geochemical analysis the authors proved that the volcanism is penetrating and is associated with the late phase of a multi periodical and tectonically eroded volcanic island arc. The authors focussed this study on the Aguas Claras and the Floro Perez ore bearing igneous rocks.

Összefoglalás – 1984-1988 között egy magyar térképező és nyersanyagkutató geológuscsoport dolgozott Kuba ÉNy Oriente-i részén Holguín körzetében a korábbiaknál részletesebb felbontásban, sok új eredményt szolgáltatva. A Bahama Platformnak a kubai része amely az Észak-amerikai kontinens lemez D-i nyúlványa – Orientében felszínre bukkanva – a rá DDNy-felől feltolt kréta ofiolitokból és vulkáni szigetív maradványokból felépülő pikkely-melange takarórendszer aljzatát képezi. A vitatott eredetű, helyenként nemesfém tartalmú polimetallikus ércesedéseket hordozó bázisos, semleges és savanyú magmás testek a szerzők véleménye szerint a szigetív köztes degradációs, illetve késői magmás fázisaihoz kapcsolódnak, s a melange-ot áttörve, annak pikkelyközi tereibe ágyazva, nagyrészt paraautochton helyzetben találhatók, környezetükkel termikus-hidrometaszomatikus kontaktusban. E tanulmány Aguas Claras és Floro Perez környéki vizsgálatok alapján genetikai állításunkat kívánja bizonyítékokkal alátámasztani.

Key words – Cretaceous volcanic island-arc, modal analysis, Oriente
Tárgyszavak – kréta vulkáni szigetív, melange, modális analízis, Oriente

Introduction

Geological mapping and raw material exploration study of NW Oriente was performed in the frame of Cuban-Hungarian cooperation. Ore bearing zones as well as exposures of structural or stratigraphic importance were studied on more detailed scale.

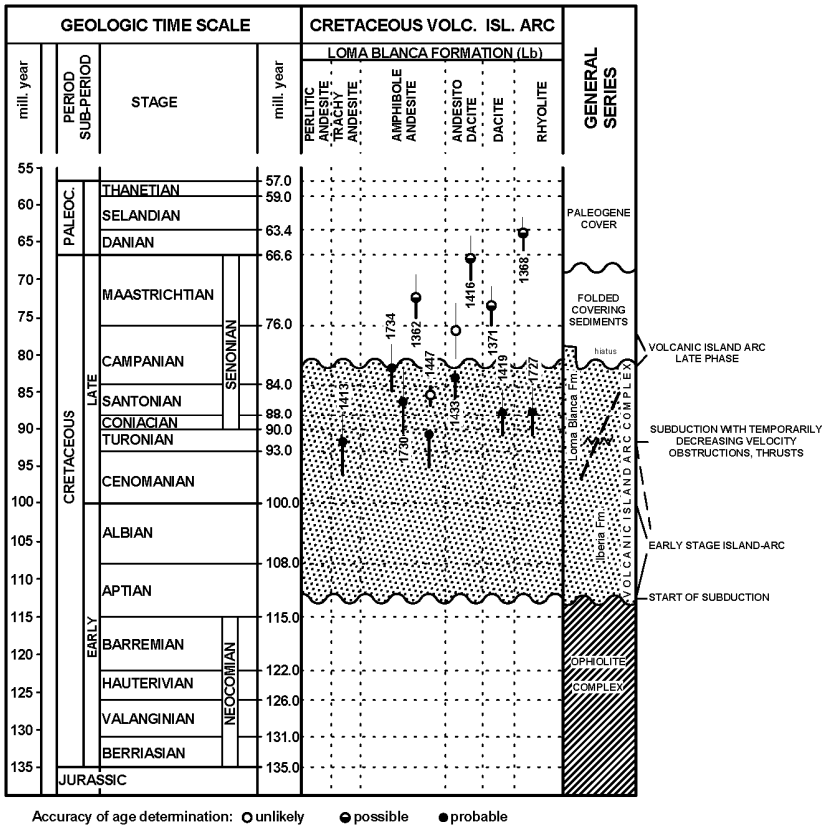

Figure 1 K/Ar radiometric ages of volcanic island arc magmatites around Holguin (after KOZÁK et al., 1990)
1. ábra Holguín környéki vulkáni szigetív magmatitok K/Ar radiometrikus koradatai (KOZÁK et al., 1990 nyomán)

This was particularly reasoned by the fact that the Caribbean oceanic basement (the ophiolite series forming the base, the fore- and back-arc basin of the Cretaceous volcanic island arc) obducted to the margin of American continent together with the penetrated and included volcanic arc formations (*Fig. 1*) (KOZÁK & ANDÓ 1987, KOZÁK 1988, KOZÁK 2000). The melange formed by this process makes the petrogenetic origin of several magmatic bodies (mainly basalts, andesites, quartz diorites, plagioclase granites, plagioclase rhyolites) problematic. Detailed exploration and field-work, rigorous study of contact zones and borehole cores, and comparative petrogenetic studies made possible to clear the origin of a formation group.

The Aguas Claras gold mineralization of debated origin is north of Holguin town. It has been known for a long time, however, has been poorly explored. Its volcanic arc or ophiolitic origin could be decided partly by using modal analysis. The mineralization is connected to lenticular magmatic bodies included by foliated serpentinite slivers found in a reverse fault of approximately E-W strike. The former authors called it on different names; some of them did not interpret their origin, and others regarded it as secondary phenomenon (*Fig. 2*).

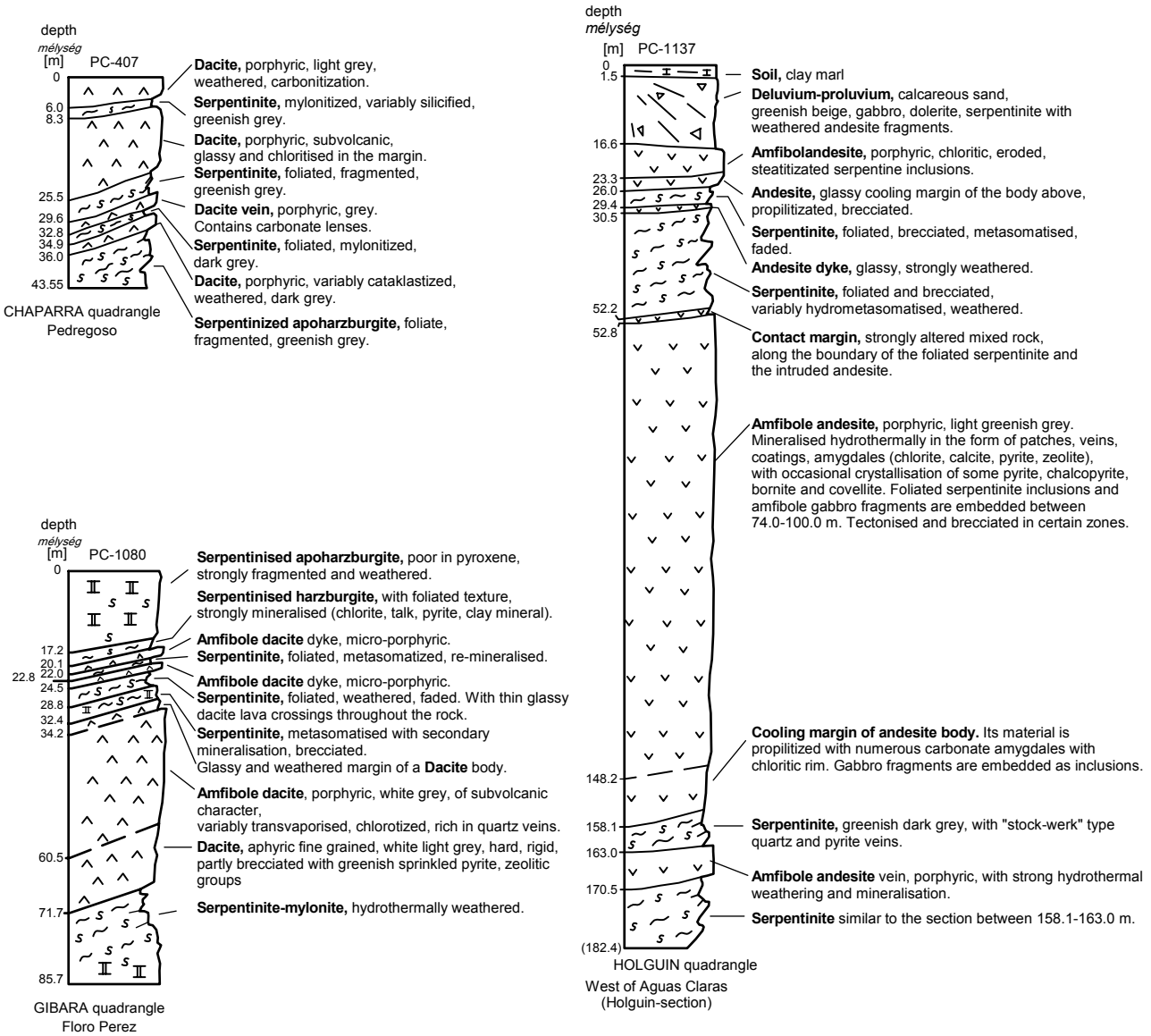

Figure 2 Characteristic borehole profiles from the surroundings of Holguín depicting the relationship of penetrative island-arc igneous bodies and the ophiolite melange

2. ábra Áttörő szigetív magmatitok és az ofiolit melange kapcsolata jellemző Holguín környéki fúrásszelvényekben

Experiences of the detailed fieldwork show that the ore bearing igneous bodies are not in genetic connection with the host environment, but have partly igneous and partly tectonic contact to it. According to their radiometric age they belong to the 'final phase' of the island-arc (Loma Blanca Formation); moreover, crucial textural and mineralogical-geochemical analyses suggest that they

represent island-arc andesites, which penetrated into the serpentinite melange under extreme conditions.

Identification of igneous bodies is not simple as they are rarely preserved in masses with extent of several hundred metres or kilometres in the structurally fragmented melange material of the area. However, occasionally relicts of the associated sedimentary environment remained as well contributing to successful identification and the comparison of facies, biochronologic and radiometric chronologic data. Dissection of greater degree affected mostly the volcanic complexes of the island arc. The igneous bodies of the subvolcanic zone have ophiolite host environment frequently making the separation of the two major genetic units difficult in the case of less differentiated magmatites. Although they presented the basis for numerous debates the most clearly separable island arc magmatites from the ophiolite series were those where in the mixed material of the ophiolite melange very different andesite and dacite intrusions or penetrations occurred with igneous or hydrometasomatic contact (*Fig. 2*).

Hydrothermal ore mineralizations

Some kilometres toward the N of Holguin town, there is a peculiar zone of the sliver-melange reverse fault of obducted ophiolite–island arc of the Bahama Platform in which the well-known Aguas Claras gold mineralization can be found. Records suggest gold exploration in the Holguin area as early as the 16th century, however, multiphase explorations and periodical small scale exploitation as the direct preliminary of the recent mining, began as late as the 19th century (CHALIY et.al. 1966, MILNIKOV & VEGA 1975, KAZAKOV et al 1974, MOCHALOV 1978, KRAMER, 1988, FÖLDESSY in PENTELÉNYI et al., 1988).

Along the strike of the reverse faults, hydrothermal gold mineralizations affected the reverse fault-like sliver-melange formations of different age and origin are located in some km long zones (*Fig. 2*). As a common feature, the gold appears in microscopic size, often as inclusion or contamination in pyrite and arseno-pyrite. Microscopic grains of some tenth millimetres can also be found in the placer of the near small rivers. Its endogene varieties accompanied by hydrothermally and metasomatically weathered, leached as well as impregnated and oxidation zones are located near the surface in tectonically oriented 5-50m thick and 10-100m long zones. The Au-concentration ranges from 0.1 to 15g/t. According to our experiences, near the ore zones there are para-autochthonous basic, intermediate and acidic subvolcanic–volcanic bodies, conduits, dykes, a part of which are proved by geophysical measurements and boreholes to be continuous toward the roots. Mineralization is located either in the igneous bodies or in the transvaporised wall-rock or both, in the form of disseminated pyrite, rarely chalcopyrite and arseno-pyrite. On the basis of this paragenesis, the mineralization can be regarded as dominantly tele- and epithermal, and, in some cases, mesothermal. Copper appears sporadically in some locations, mainly where the wall rock is ophiolite.

Different hypotheses have been assumed about the origin of this mineralization:

1. Former studies (CHALIY et al. 1966; MILNIKOV & VEGA 1975; KAZAKOV et al. 1974; MOCHALOV 1978) regarded it as near-surface hydrothermal re-activation of the allochthonous rock-mixture.
2. Members of the Hungarian expedition outlines three different opinions:
   - According to ANDÓ (in Pentelényi et al. 1988, ANDÓ J. 1993) the gold mineralization is connected to the ophiolite formations. He suggests that the questionable hydrothermal zones are local auto-metasomatic phenomena of the primary ore mineralization, which connects to diorite series and quartz keratophyre volcanism of gabbro cumulate of the ophiolite becoming allochtonous position by tectonic motions.
   - According to FÖLDESSY (in Pentelényi et al, 1988) their appearance can be connected to a tectono-magmatic event happened in the Cretaceous-Paleogene boundary (i.e. after the ceasing of the northern volcanic island arc), and he cites COBIELLA (1988), who assumes this kind of Paleogene activity in the area.
   - KOZÁK (1988, 2000) reconstructed the 30-million years development of the Cretaceous island arc, and connects the mineralization to it as the tectonically most characteristic intra- and post-genetic event of the magmatism of the Loma Blanca Formation ('final phase'). This paper shows evidence of this hypothesis, and outlines some results.

In the vicinity of the ophiolite melange, there are such igneous bodies, andesitic and dacitic in composition occurring in penetrative position in which ore mineralization is minimal. However, interference with surface or subsurface waters and thus variable alteration can be detected in these cases as well. Their inclusions contain both ophiolite melange clasts and fragments of island arc material. The repeated intrusion of the magma rose up to volcanic-subvolcanic levels along breccia and foliated serpentinite zones into the structurally orientated melange (*Fig. 2*). The margin of the thicker intrusions is glassy or micro-porphyric or it has chloritized cooling rim. In the case of thinner (0.1–1m) dykes it is usually entirely glassy and propylitized, faded.

Based on the position, the assumption seemed to be justified that the igneous bodies in question are younger and not part of the ophiolite series.

Modal analytical results

A part of the andesites and dacites appearing in the boreholes were formerly interpreted as hypabyssal intrusions. In contrary, our observations revealed volcanic-subvolcanic origin, therefore modal analyses were performed to obtain evidence for either interpretation.

The authors took part in the elaboration of an effective and improved modal analytical method (JÁRAI et al., 1996; 1997). Using this method in microscopic

measurements, mineralogical composition and textural features of a rock can be simultaneously determined with a minimum probability of 65%. The quantitative analysis is performed by measuring along the parallel reference lines at a distance (*d*) from each other, which longer than the maximum diameter of the mineral grains; this way one grain is measured on one line. On the basis of the summarized data, the grains can be distributed into mineralogical groups and grain-size intervals, and the result can be graphically demonstrated.

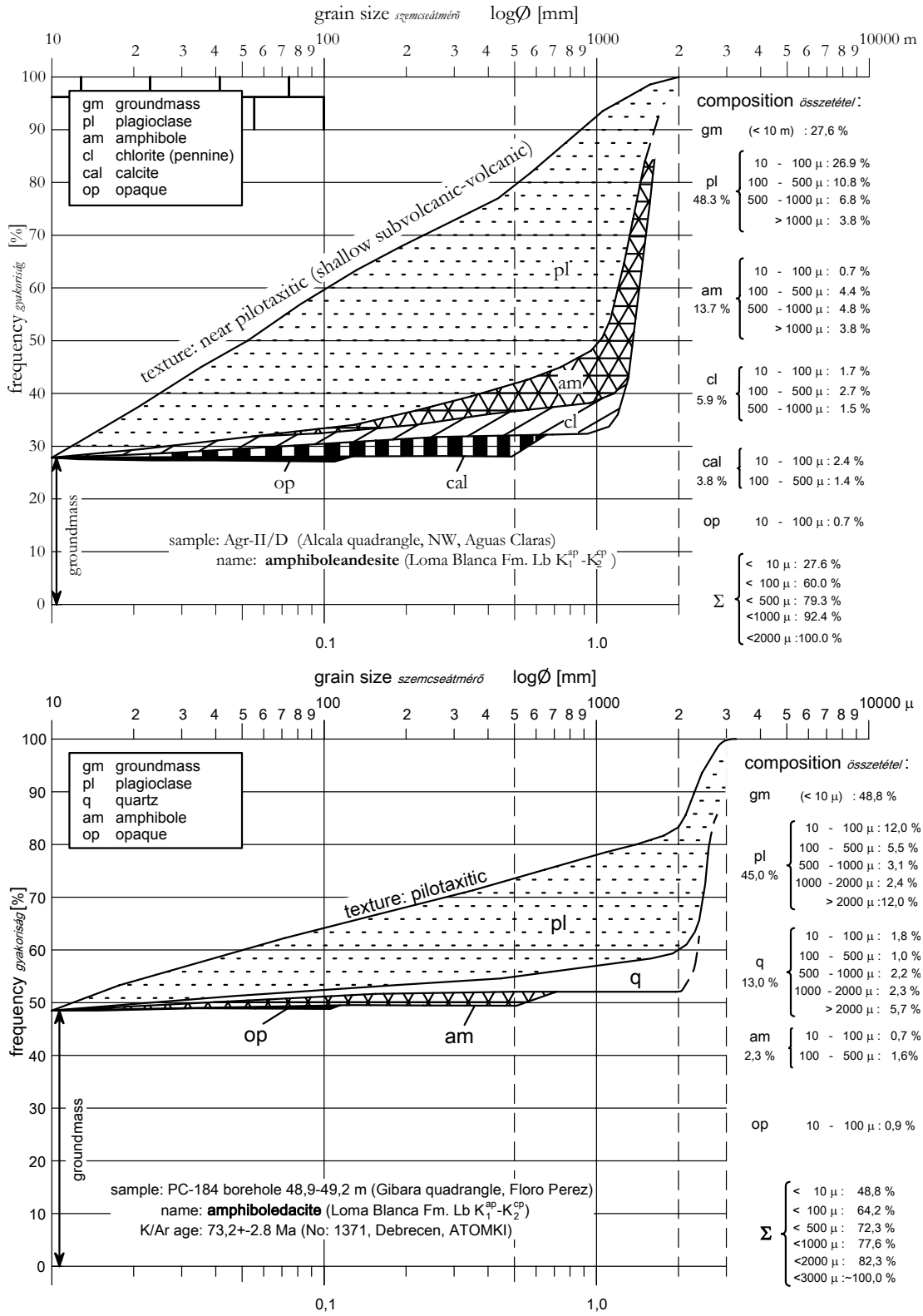

Figure 3 Modal analysis of rock samples from ore bearing igneous bodies in northwest Oriente
3. ábra Érchordozó magmás testek kőzetanyagának modális elemzése ÉNy Orientében

To determine with relevant probability the maximum diameter (d_j) of the grains in the jth fraction, the maximum ratio of which to the total material is p_j, then C constant depending on d and p is

$$c \le \sum_{j=1}^{m} p_j \cdot d_j \qquad (1)$$

The C constant can be experimentally determined, too. To determine p with a probability of 1-δ at most with error ± Δp measurements must be performed with a total length at least

$$h = c \cdot \left(\frac{a}{\Delta p} \right)^2 . \qquad (2)$$

Where 'a' is the distance between the cut planes of the applied thin sections

Using this method, grain-size and mineral composition of some samples from the igneous bodies of debated origin were determined (*Fig. 3*).

Position of these samples in the groundmass-silica diagram (RÓZSA & PAPP 1989) suggests their volcanic or shallow sub-volcanic origin (*Fig. 4*).

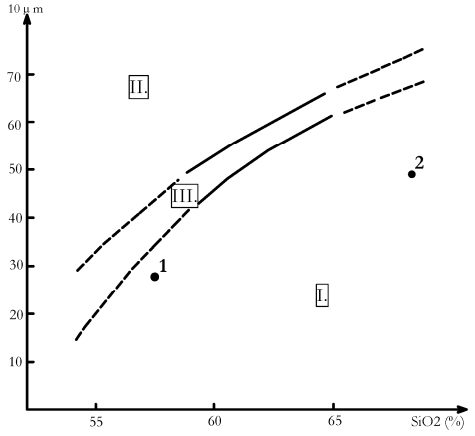

Figure 4 Position of the samples in the groundmass-silica diagram I. Subvolcanic field, II. Volcanic field, III. Transition zone, 1. amphibole andesite, 2. amphibole dacite
4. ábra A minták helyzete a mikroszkópban kimért alapanyag és a kovasav % függvényrendszerben I. Szubvulkáni mező, II. Vulkáni mező, III. Átmeneti zóna, 1. amfibólandezit, 2. amfiboldácit

This grain-size distribution pattern can be regard as the first evidence for the hypothesis that the penetrating para-autochthon andesite from Aguas Claras and the dacite from Floro Perez, and other igneous bodies are not in direct magma-genetic connection with the tectonite serpentinite of host melange and with the sporadically fragmented allochthonous gabbro blocks.

Geochemical results

In the petrogenetic distribution of the volcanic island-arc, amphibole andesites were classified into the so-called group IV (Aguas Claras and Cuatro Palmas). Volcanic rocks in the Cuatro Palmas exploration sector (Santa Lucia area) are generally Na-rich, while andesites in the environment of Aguas Claras (map sheets of Holguin and Alcala) rarely show Na-accumulation, and can be characterized by varying K content. The open cast mines of the Aguas Claras gold mine are called Agrupada, Nuevo Potos and Reina Victoria.

The Aguas Claras gold mineralization is connected to an igneous mass of oriented amphibole andesite bodies of E-W strike between serpentinite melange slivers. Although these bodies rose simultaneously and in similar ways, their alkali content is significantly different. Potassium content of the rock from the Reina Victoria open pit is relatively high (K_2O content of the sample 7-2-54/5: 3.1%); that of the rock in the Nuevo Potos mine is lower but varying (K_2O: 0.85–1.61%), while it is quite low in the rock from the Agrupada mine (K_2O: 0.16–0.22%). The K/Ar radiometric age data show some scatter (KOZÁK et al., 1990); analytical data of the rock from Nuevo Potos (81.2+/-3.3Ma) can be regarded as the most relevant one, while rock from Agrupada seems to be older (86.1+/-4.5Ma) because of metasomatic potassium loss.

Trace element content of andesite sample from borehole PC-1137 in the Aguas Claras was determined by using ICP-MS and ICP-AES technique in the Hungarian Geological Institute (MÁFI). The spider diagram of CI chondrite normalized trace elements distribution of the andesite is shown in *Figure 5*.

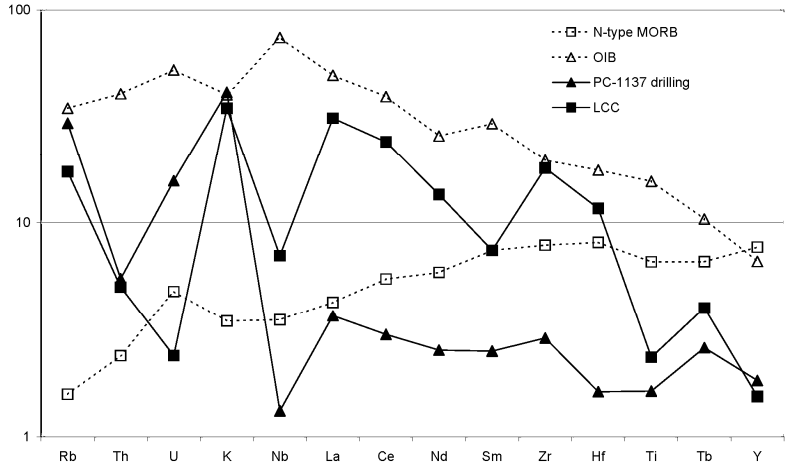

Figure 5 CI chondrite (MCDONOUGH et al. 1991) normalized trace element distribution of the andesite sample from borehole PC-1137 in Aguas Claras, N-type MORB (SAUNDERS & TARNEY 1984), OIB (SUN 1980) and LCC (WEAVER & TARNEY 1984)
5. ábra Az Aguas Claras területen mélyült PC-1137 sz. fúrásból vett andezit minta, az N típusú MORB (SAUNDERS &TARNEY 1984), az OIB (SUN 1980) és az LCC (WEAVER&TARNEY 1984) CI kondritra (MCDONOUGH et al. 1991) normált nyomelem eloszlása

Distribution pattern of this sample is characterized by maximal peak of potassium, relatively high peak of Rb and Zr, maximum depletion in Nb, and relative depletion in Ti; these features as well as its general pattern are quite similar to that the average lower continental crust (LCC), and significantly differs from that of ocean island basalt (OIB) and middle ocean ridge basalt (MORB).

Other evidences for the island arc origin

Several exploration boreholes traversed the igneous bodies (*Fig. 2*), which show features (cooling margin, para-autochthonous position, contact zone, melange host rock, etc.) supporting their assumed island-arc origin.

In the vicinity of Holguín numerous features suggest that igneous activity did not cease completely following collision and imbrication, furthermore slight re-activations may have occurred in the Paleocene according to the K/Ar age data.

Detailed modal analysis of the rock formerly called diorite-porphyrite (*Fig. 3*) proved that it represents an amphibole andesite crystallized at shallow sub-volcanic depth. Its igneous (hydrothermal metasomatic) contacts can be well observed within the highly tectonized, sometimes foliated, host serpentinite. As microscopic studies revealed, the andesite bodies have a 20-40cm wide glassy cooling margin, which suffered significant chloritization due to the hydro-metasomatic alteration. This greenish black chloritized zone may extent 10-20cm in width, and it can be scratched by nail. The X-ray diffraction analysis of the andesite sample from the chloritized zone of the contact in the Agrupada mine indicates 64% chlorite and 4% gibbsite content. In this locality, in the first meters from the foliated contact the tectonite serpentinite shows strong coloring and discoloration in the form of brownish and creamy zones at the boundary of the andesite body. Along the contact zones of silification and carbonate, pyrite (and brown ironstone) mineralization can be observed. The isolated gabbro and diorite blocks enclosed by the serpentinite also suffered alteration near the contact. However, they are not in direct petrogenetic connection with the amphibole andesite.

More than 220 major-element and several trace element analyses, and some X-ray diffraction studies (KOZÁK 1988) make possible to reveal petrogenetic relationship of the island arc remnants, which are tectonically isolated and enclosed in melange. These studies suggest that the petrographically distinct petrogenetic rock-groups are in geochemical relationship to each other. Their geochemical variability, similarly to other areas of Cuba (e.g., Camagüey, Las Tunas), depends on whether they belong to rock assemblages of the primitive island-arc (Iberia Formation) or the matured arc (Loma Blanca Formation), of the intermediate (Turonian) or the final (Campanian-Maastrichtian) tectogene degradation phase (*Fig. 6*).

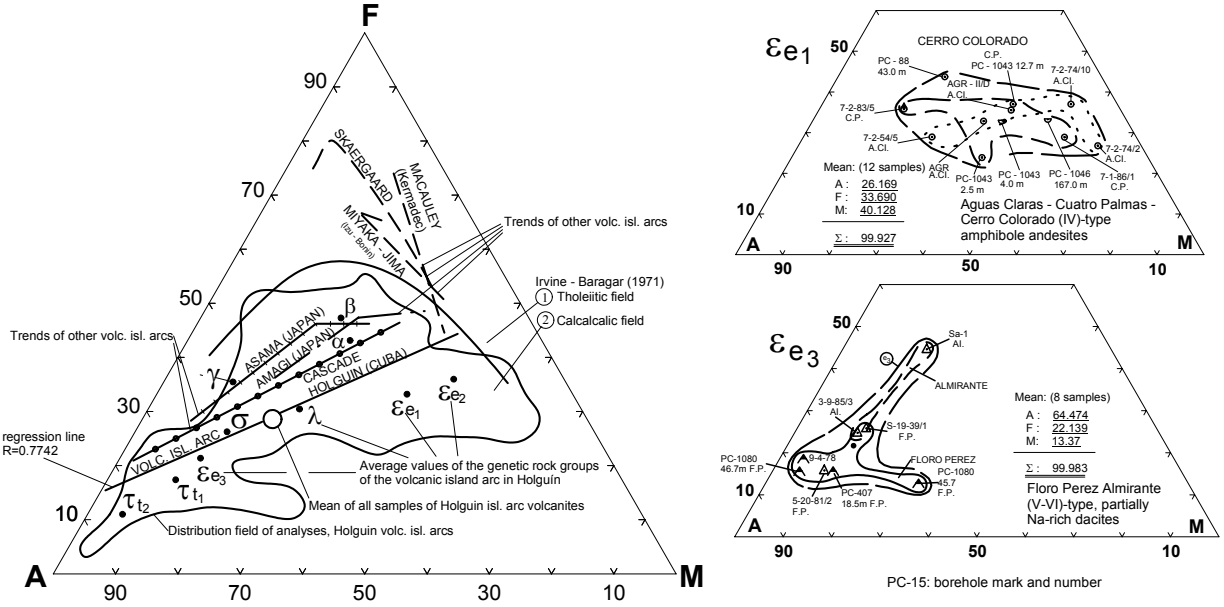

Figure 6 General geochemical characteristics and distribution fields of the Cretaceous volcanic island-arc in NW Oriente in the AMF diagram with some localities of the „final" igneous bodies penetrating the melange highlighted (right)
6. ábra ÉNy Oriente-i kréta vulkáni szigetív általános geokémiai jellegei és eloszlásmezője az AMF diagramban a melange-ot áttörő „finális" magmatitok néhány előfordulásának kiemelésével (jobbra)

As it can be seen in the AMF triangle on the left of *Figure 6* most of the magmatites of the Cretaceous volcanic island arc of NW Oriente are of calc-alkaline character. Besides a few tholeiitic and shoshonitic formations can be found as well. Relatively extensive distribution field indicates the multiphase and variable character of island arc formation. Such variability can be also observed elsewhere in Cuba (e.g. Las Tunas, Camagüey), however, there the formations are not melange, thus the direct genetic relationship of the bodies can be detected better and development phases can be separated easier. The average value and regression line calculated on the basis of every analysis can be compared to the volcanic island arc

subsystems of the Cascade Mountains in North America and the Amagi volcano in Japan.

The AMF diagrams on the right side display the geochemical character of the argued andesitic-dacitic bodies. As it can be seen, the character of the andesite bodies in Aguas Claras and the andesite, andesite-dacite and dacite bodies near Floro Perez show great similarities. However, differences are experienced elsewhere, presumably these can be the results of interaction with the host rocks (contamination, transvaporisation).

The term "final" is applied on the volcanics in question due to two reasons. First, the very young age of a part of these bodies extending over the age of the closing stage of island arc formation accepted and justified generally. Second, both in the case of the older and younger series the volcanic-subvolcanic bodies are associated to such thrust, foliated and brecciated tectonite-serpentinite melange the identical petrogenesis of which can be excluded.

This may happen in the course of island arc development as it is suggested by the crust dissection and degradation processes in the Turonian. This gradual slowing and temporary and then permanent stabilization results in the compression, thickening, folding at places and breaking of the front and foreland of the moving plate with thrusts of variable angle and volume. These may enable the assumption that partial melts may be generated along the crust-mantle boundary.

PARDO (1990) called attention to tectonic-magmatic re-activation in the Campanian-Maastrichtian – Lower-Paleogene simultaneous with the regional metamorphism in the area of Isla de la Juventud. He points this process as the primary reason for endogenous metalogenesis. Subvolcanic bodies with acid character together with strong hydrothermal and metasomatic impregnation zones were formed along the fragmented, brecciated fault zones of the extended elliptic metamorphic body. Within these vein-like mineralization, silification and wolfram mineralization occurred. The age of the magmatism mentioned by PARDO (1990) was recorded as 60-68Ma as measured in the material of a subvolcanic body like this.

Results and summary

Shallow sub-volcanic origin of the penetrating, oriented, frequently chloritized igneous bodies was firstly proved by modal analytical studies. In our opinion, this origin excludes the petrogenetic relationship between these igneous bodies and the adjacent foliated tectonite serpentinite as well as gabbro bodies. Trace element distribution pattern of andesite sample from the borehole PC-1137 indicates significant similarities to that of lower continental crust. This conclusion was supported by K/Ar radiogene isotope studies on the fresher part of the rocks. Moreover, geochemical variability of these bodies suggests that features and size of the contamination, the mineralization and the hydrometasomatic aureoles were determined by interaction with the host rock. This way, although these igneous bodies have island-arc character, they may contact tectonite serpentinite and gabbro blocks just as in-arc breccias and melange zones or island-arc remnants. Closeness of the sea and the occasional shallow-water sub-aquatic character of the magmatism may explain the intensive water-rock interaction and the simultaneous thermo-gravitational water circulation in the reverse fault zones.

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