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Christian Juberthie et Vasile Decu

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AZORES

by

Paulo A. V. BORGES * and Pedro OROMÍ**

I - THE AREA

The Azorean archipelago is located in the North Atlantic, at the triple junction of the Eurasian, African and North American plates. The distance between the Azores and the mainland is about 1390 km, calculated from Cabo da Roca (the most westerly point of the European continent). It is formed by nine volcanic islands, aligned on a WNW-ESE trend, which are distributed in three groups: the occidental group of Corvo and Flores; the central group of Faial, Pico, Graciosa, São Jorge and Terceira; and the oriental group of São Miguel and Santa Maria (Fig. 1).

The largest island is São Miguel (757 km^2), and the smallest is Corvo (17 km^2). Santa Maria is the most southerly island (37° N, 25° W), and Flores is the most westerly one (31° W). The most northerly one is Corvo (39,7° N) (see Tabl. 1 and Fig. 1). All the information concerning the longitude (long.), latitude (lat.), area, maximum altitude and geological age of each island are given in Tabl. 1.

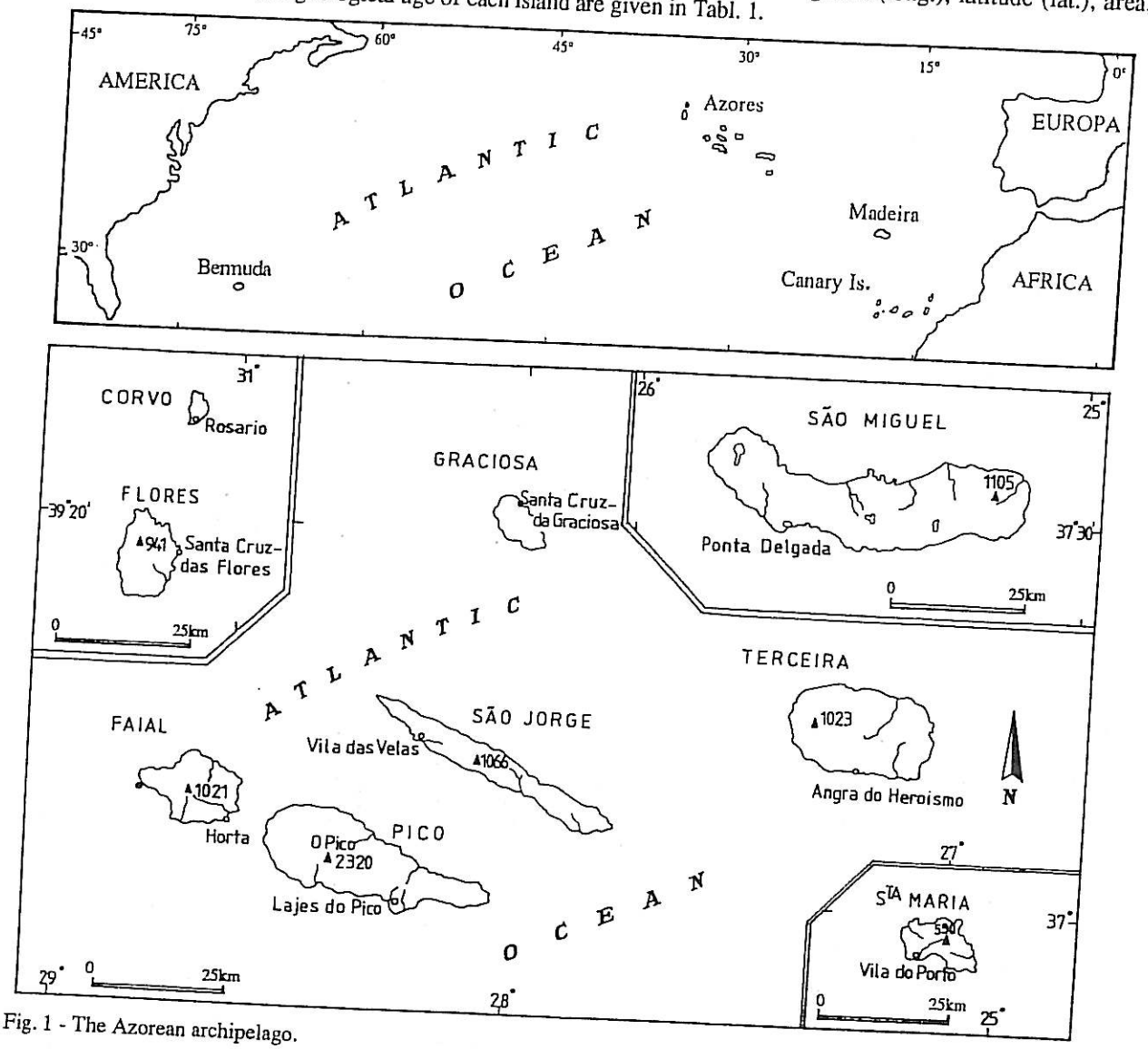

Fig. 1 - The Azorean archipelago.

*Universidade dos Açores, Departamento de Ciências Agrárias, Terra Chã, 9702 Angra do Heroísmo, Terceira, Açores, Portugal.
**Departamento de Biología Animal (Zoología), Universidad de La Laguna, La Laguna, 38206, Islas Canarias, España.

There are many examples of historical volcanic eruptions (vide WESTON, 1964). The geostructural environment of the Azores Plateau, defined by the 2000 meters bathymetric curve, is dominated by the confluence of the American, Eurasian and African lithospheric plates. This tectonic feature is responsible for a remarkable seismovolcanic activity from which the Capelinhos eruption (Faial island - 1957/58) and the 1st January 1980 earthquake (epicentral location 30 km W of Terceira island - Magnitude 7.2) are the most recent catastrophic events (GASPAR *et al.*, in press).

The geological age of the nine islands is very dissimilar. Because their formation took a long period of time, these islands present a recent volcanic morphology (e.g. Pico) or more eroded, ancient formations (e.g. Flores and S. Maria). There are several sudies concerning the geological dating of the Azorean islands, but unfortunately there is no agreement concerning the age of some islands. Three alternatives are proposed (see Tabl. 1).

The acceptance of the Plate Tectonic mechanisms and the confirmed volcanic origin of the Azores, made the Azores a totally oceanic archipelago. The eastern part of every Azorean island is, geologically, the oldest one. This is connected with the seismovolcanic mechanisms of this archipelago (FORJAZ, pers. comm.).

Tabl. 1. - Comparisons of the physical characteristics of the nine Azorean islands. A : FORJAZ (pers. comm.); B : ABDEL-MONEM *et al.* (1975) and FERAUD *et al.* (1980); C : QUEIROZ (1990).

Islands	Long. (W)	Lat. (N)	Area (km^2)	Alt. (m)	Age (MA)		
					A	B	C
Corvo	30.8	39.7	17	718	?	?	?
Flores	30.9	39.4	142	915	0.01	0.62 (2.9)	1.80
Faial	28.5	38.6	172	1043	2.60	0.73	0.73
Pico	28.2	38.5	433	2351	1.10	0.037	0.037
Graciosa	27.8	39.1	62	402	0.62	0.62	2.50
S. Jorge	27.9	38.7	246	1053	2	0.55	0.55
Terceira	27.2	38.7	402	1023	2	0.30	2
S. Miguel	25.5	37.7	757	1103	4	4.01	4.01
S. Maria	25.1	36.9	97	587	8	8.12	8.12

Located at a mean latitude of 38° 30' and surrounded by the Atlantic Ocean, the Azores enjoy the benefits of a mild and agreeable climate. The influence of the warm Gulf Stream is important, allowing temperatures at sea level to be quite similar in the southeastern and in the northwestern islands; the same can be said of the humidity (AGOSTINHO, 1966). Low thermal amplitude, high precipitation and humidity are properties of this archipelago, with its marked oceanic climate.

In spite of the three groups of Azorean islands being separated from each other by sea channels 1000 to 2000 m deep, the channel between Faial and Pico has zones only 20 m and 50 m deep (BERTHOIS, 1953). It is therefore possible that at the height of the glaciation about 18,000 years ago, the lowering of the sea level could have permitted a terrestrial passage between these islands (EASON and ASHMOLE, 1992). Estimates of the glacial sea level range from less than 80 to over 130 m below the present level (BLOOM, 1971).

It seems probable, simply by virtue of the fact that the Azores is the most septentrional archipelago of Macaronesia, that it should have suffered in part the influence of the glaciations (ISRAELSON, 1990). However, COOPE (1986) affirmed that the fauna and flora of the Azores (and of the other southern Macaronesian archipelagoes) have not been subjected to the repeated exterminations and recolonizations that were imposed upon those of more northerly Atlantic islands (e.g. the Shetlands, the Faeroes, Iceland and Greenland) by the comings and goings of the polar front (see also BORGES, 1992).

II - THE ENVIRONMENT

The Azorean archipelago is a region with several very recent historical lava flows with a great concentration of lava tube caves and pits. All the main volcanic lava tubes are situated in *pahoehoe* basaltic lava flows (FORJAZ, 1963). They are built by very fluid lavas under special conditions, appearing in most of the Azorean islands, namely Pico, Faial, Terceira, Graciosa, S. Jorge and S. Miguel.

In fact, this islands are formed mainly by volcanic rocks with a dominance of basaltic lavas of the basic type, forming *pahoehoe* lava fields. It is also common to find lava flows of *aa* type wich are very rough and known locally as "mistérios" or "biscoito". The mechanism of formation of the lava tubes mainly consists in rapid cooling and solidification of the upper surface, developing a porous and hard crust while lava is drained under it, leaving a lava tube (FORJAZ, *op. cit.*).

As already pointed out, in the Azores there are several historical lava flows. For instance, in Pico there are areas with a great concentration of lava tubes and pits. The Mistério of S. Luzia (1718) is the Pico lava flow with a larger number of lava tubes. Probably some of them are remain of a unique longitudinal tube (BORGES *et al.*, in press). In Mistério of Silveira (1720) there is a remarkable lava tube, Gruta do Saldão (1150 m length), a simple "unitary" or "throughway" type lava tube (*sensu* HALLIDAY and LARSON, 1983) excellently

preserved. Up to now 28 lava tubes and 8 pits are known from Pico, occurring the longest lava tube from the Azores in this island, Torres'Cave, with 3350 meters long (BORGES *et al.*, in press).

Terceira is doubtless the second most important Azorean island, after Pico, regarding to the occurrence of lava tubes and pits, with several areas with caves of great interest. The Pau Velho lava flow(1761) is probably the area with most interesting caves from this island, where is found Gruta dos Balcões, the second longest lava tube from the archipelago, with 2713 meters long (BORGES *et al* , *op. cit.*). These caves have a moderate importance from the entomological point of view, because most of them are covered by pasturage and there is some mud impermeabilization. Nevertheless, the relict cave carabid *Trechus terceiranus* Machado can be found in Balcões and Caldeira lava tubes (BORGES and OROMÍ, 1991). Probably the most impressive cave in this island is Algar do Carvão, a remarkable volcanic chimney developed as show cave since 1988.

In São Jorge there are two lava tubes (Gruta da Beira and Gruta do Leão) and two pits (Bocas do Fogo and Algar do Montoso) of great interest, not only because their speleological structures but also because of their unique fauna. Gruta da Beira is a lava tube also affected by impermeabilization and thus with a poor fauna, but the endemic cavernicolous pseudoscorpion *Pseudoblothrus oromii* Mahnert and an undescribed cave isopod can be found there (OROMI *et al.*, 1990). Algar do Montoso is a huge volcanic pit situated at 900 m a.s.l., in a wet peat bog zone of this steep island. It is still poorly studied, mainly due to the hard weather and the difficult access to the hole .

Faial has the remarkable volcanic chimney Furna Ruim, the third bigger vertical of the Azorean pits (55 meters) but with hardly any completely dark place; anyway, the penumbra and high humidity are enough to hold a few troglobites. Besides there are a few small lava tubes but with some striking hypogean endemic arthropods.

In S. Miguel all the main caves are located in the recent part of the island, the central plateau geologically known as "Picos Volcanic Complex" (see NUNES and BRAGA, in press). Most of them are small and very spoiled, mainly because of the above commented soil erosion under pasture lands. In spite of that, some caves like Gruta de Água de Pau have a worth noticing fauna, probably because of the ancient age of island (4.01 Ma according to ABDEL-MONEM *et al.*, 1975).

S. Maria is the oldest island of the archipelago (8.12 Ma) (ABDEL-MONEM *et. al., op. cit.*) without recent lava flows. It has only littoral caves of sea erosion (e.g. Anjos and Pombas) and no adapted fauna has been found there.

Graciosa is still poorly studied, but in this island occurs the beautiful Furna do Enxofre, an enormous volcanic pit with a large lake at the bottom and solfataras that periodically become more active, creating bad air conditions (see also GASPAR *et al.*, in press).

In the smallest of two occidental islands, Corvo, there is the record of one cave, presently closed. Flores is a middle aged island with no very recent eruptions, therefore lacking lava flows and tubes.

After BORGES *et al.* (in press) the number of known caves and pits from the Azorean islands are: Corvo (1 : -), Flores (- : -), Faial (3 : 1), Pico (28 : 8), Graciosa (16 : 1), S. Jorge (7 : 5), Terceira (20 : 6), S. Miguel (10 : 3) and S. Maria (3 : -).

Besides the proper caves, another type of subterranean habitat can be found in more ancient areas (several million years old) where lava tubes have already been destroyed. Indeed in the island of S. Maria one can find troglobites adapted to live in the M.S.S. ("Milieu souterrain superficiel") (BORGES, 1993). A similar type of habitat occurs in more recent areas, what OROMÍ *et al.* (1986) have called "volcanic M.S.S."; on the slopes of Serra de Santa Bárbara (only 10,000 years old) in Terceira , BORGES and OROMÍ (1991) made the first record of a troglobitic species (*Trechus terceiranus* Machado) for the M.S.S. in the archipelago. Since then, we have collected other species in this habitat on the same island; most of them have not been yet studied, but the hypogean centipede *Lithobius obcurus azoreae* was recently recorded for the M.S.S. of Terceira by EASON and ASHMOLE (1992) (see also BORGES, 1993).

Like in other volcanic areas (e.g. Hawaii, Canaries) also it can be found on the Azores a particular habitat formed by recent lava flows, where there is a complex network of cracks and holes. This habitat is occupied by communities of lavicolous animals supported by the fallout of aerial plankton on the surface (ASHMOLE and ASHMOLE, 1987). While in the Canaries some relationships between this fauna and that of neighbouring lava tubes has been demontrated (ASHMOLE *et al.*, in press), this is not the case for the Azores.

III - THE FAUNA

Cave arthropod collections from the Azores have been made only recently, being the first hypogean species described a few years ago (MACHADO, 1988). The biospeleological campaigns can be resumed as the following ones: two directed by N. P. ASHMOLE (Edinburgh University) and one of the authors (P. OROMÍ) and supported by the National Geographic Society, USA (July - August 1987 and 1989, the latter also with the participation of the junior author, P. BORGES); two expeditions of the Speleological group "Os Montanheiros" to the island of Pico in May 1989 and March 1990 with the participation of one of the authors (P. BORGES); an expedition carried out by one of us (P. BORGES) in April 1990 to S. Miguel.

Many of the cave species known to occur in the Azores belong to genera that have representatives in the troglobitic fauna of the Canaries (OROMÍ *et al.*, 1990), also an archipelago of volcanic origin and situated in the same biogeographic area (Macaronesia). This is so in the case of the ground beetles *Thalassophilus azoricus*

Oromí and Borges with some epigean and cavernicolous relatives in the Canaries and Madeira; the *Trechus* spp. belong to the *T. tingitanus* species group (OROMÍ and BORGES, 1991) with some related species in the Canaries like *T. benahoaritus* Machado and *T. miniocultatus* Machado (BORGES and OROMÍ, 1991). Also the centipede *Lithobius* and the planthopper *Cixius* are genera represented in the Canaries by several related species, and the same is true to the collembolan genus *Pseudosinella* that has cavernicolous species in the Canaries (GAMA, 1988) but these species seem to be just troglophiles.

The family Trichoniscidae (Isopoda) is represented in the hypogean environment of the archipelagoes, although by species belonging to distinct genera and showing different degrees of adaptation (see OROMI *et al*, 1990). The Azorean cave-dwelling trichoniscid is found in S. Jorge and belongs to a new genus not yet described. The other terrestrial cave crustacean is *Macarorchiesta martini* Stock, which occurs near the entrance of a cave where sea water arrives when the waves are big. Their adaptations to the underground are not very remarkable (STOCK, 1989).

Constrasting with the Canaries is the fact that most of the Azorean troglobites belong to genera without related epigean species now living in the archipelago (see Tabl. 2). As a consequence of the absence of surviving epigean close ancestors in the same island, we can say that these troglobites are local relicts. In some cases like *Thalassophilus azoricus* and the two cave-dwelling *Pseudoblothrus*, no congeneric epigean species are known at all on the Azores, being then considered as regional relicts. Although similar situations can be found in the Canarian cave fauna, the proportion of relictic species is considerably smaller, many of the troglobitic species having closely related species living on the same island, often enclosed in endemic genera (OROMÍ and IZQUIERDO, in press).

There are however some exceptions to this rule in the Azores, being the case of the centipede genus *Lithobius* and of the homopteran *Cixius* spp., with some related epigean species living in the same island. However, the only hypogean centipede *Lithobius obscurus azoreae* is not an advanced troglobite, just showing evident but moderate eye reduction and lengthening of appendages, and occurring mostly in the underground but sometimes on the surface. This phenomenon is not rare on these islands, where several troglobiomorphic species like *Thalassophilus azoricus* and *Trechus terceiranus* have been collected at the entrance of caves even during the day. But the climate is very humid and with mild temperatures, what probably explains this particular behaviour.

A cave-dwelling diplura is known from a lava tube in São Miguel, but their identity as *Campodea taurica* Silvestri has to be confirmed, since this is a species only known from caves of Crimea (SENDRA, pers. comm.)

Tabl. 2 - Cave-adapted terrestrial arthropods from the Azores. The islands in which they occur and the existence of epigean congeners in the same or in other islands are indicated (*= endemic genera).

Species	Islands	Congeneric spp.	
		same	other
Pseudoscorpiones			
Pseudoblothrus oromii Mahnert	S. Jorge	no	no
Pseudoblothrus vulcanus Mahnert	Terceira	no	no
Araneae			
Rugathodes pico (Merrett and Ashmole)	Pico/Faial	no	yes
Amphipoda			
**Macarorchestia martini* Stock	Terceira	no	no
Isopoda			
Trichoniscidae *n. gen. n. sp	S. Jorge	no	no
Chilopoda			
Lithobius obscurus azoreae Eason and Ashmole	Terc./Pico/Faial	yes	yes
Collembola			
Onychiurus sp.	Terceira/Pico	no	no
Pseudosinella ashmoleorum Gama	Terceira/Pico	no	no
Diplura			
Campodea aff. taurica Silvestri	S. Miguel	?	?
Homoptera			
Cixius azopicavus Hoch	Pico	yes	yes
Cixius cavazoricus Hoch	Faial	yes	yes
Coleoptera			
Thalassophilus azoricus Oromí and Borges	S. Miguel	no	no
Trechus terceiranus Machado	Terceira	no	yes
Trechus picoensis Machado	Pico	no	yes
Trechus jorgensis Oromí and Borges	S. Jorge	no	yes
Trechus montanheirorum Oromí and Borges	Pico	no	yes

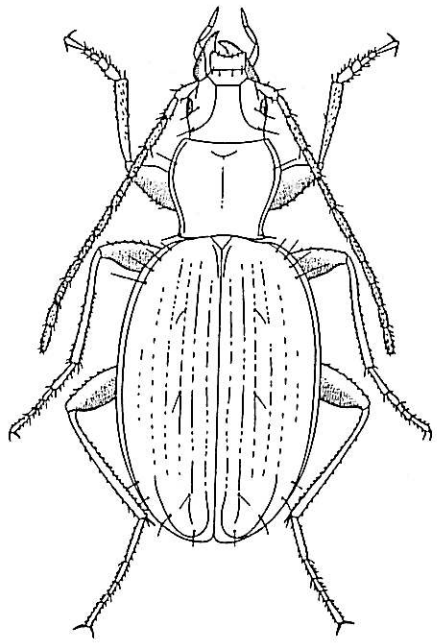

Fig. 2 - *Trechus picoensis* Machado (reprinted from Machado, 1988). Long. = 5,3 mm.

One notable case is the peculiar distribution of the two closely related ground beetles *Trechus picoensis* and *T. montanheirorum*. These species live in Pico in the same lava tube "Gruta dos Montanheiros", occurring in sympatry only near the entrance to the cave, and show different degrees of troglobiomorphy (integument depigmentation and reduction of eyes). Recently HOCH and HOWARTH (1989) presented a similar case in two new cave dwelling species of a new Australian cixiid genus (Homoptera: Fulgoroidea). *T. picoensis* (fig. 2) is regarded as being troglobitic (obligatory cavernicole), and *T. montanheirorum* as being troglophilic (facultative cavernicole). As OROMÍ and BORGES (1991) pointed out, some of the most obvious differences between the two species are those relating to adaptation to cave life which are more marked in *picoensis;* some their differences like those of the male genitalia and chaetotaxy have probably evolved without relation to the hypogean environment. It is considered likely to be the result of a single invasion into the cave environment, being sister-species (BORGES and OROMÍ, 1991).

Concluding, we can say that the Azorean cave fauna is still in a poor stage of knowledge and probably some more hypogean species will be discovered soon. Also the following list of Azorean caves with biological interest should be protected and better studied: Anelares, Cabeço do Canto and Furna Ruim from Faial; Torres, Montanheiros, Soldão, Henrique Maciel, Capucha, Arcos, Gruta dos Esqueletos from Pico; Gruta da Beira, Algar do Montoso and Algar das Bocas do Fogo from S. Jorge; Balcões, Coelho, Caldeira, Queimada, Agulhas, Madre de Deus, Santo António, Algar do Carvão from Terceira; Água de Pau and Esqueleto from S. Miguel.

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