PETROGRAPHY OF EXOTIC CLASTS IN THE SOEBI BLANCO FORMATION, BONAIRE, NETHERLANDS ANTILLES

Franco URBANI [1,2], Sebastián GRANDE [2] & José MÉNDEZ BAAMONDE [3]

[1] Fundación Venezolana de Investigaciones Sismológicas, Caracas. [2] Universidad Central de Venezuela, Facultad de Ingeniería, Escuela de Geología, Minas y Geofísica. [3] Universidad Central de Venezuela, Facultad de Ciencias. Instituto de Ciencias de la Tierra. Ciudad Universitaria. Caracas. Email: furbani@funvisis.gob.ve.

ABSTRACT

The Paleocene Soebi Blanco Formation in the island of Bonaire in Southeastern Caribbean has attracted the attention of geologists since 1931 when P. J. Pijpers pointed out the presence of a wide range of “foreign pebbles” in conglomerate beds. Interest was further boosted in 1986 with a Grenvillian age determined in a granulitic pebble (ca. 1150 Ma, U-Pb, TIMS, zircon) letting the authors propose an eastward translation of at least 300 km for the island of Bonaire relative to Guajira. New petrographic analysis of 21 rounded pebbles resulted in a wide span of rock types from metatrondhjemite, gneisses, metadiabase, andesitic lava and tuff, epiclastic metasedimentary, metapsamite, ultramylonitic marble, quartz arenite, conglomeratic sandstone and limestones (wackstonte, packstone). The variety of rock types support a combined arc-continental source region, a condition that was met in the northwestern corner of South America during Paleocene times.

Key words: Conglomerate, foreign pebbles, Paleocene, Eocene.

RESUMEN

Petrografía de los clastos exóticos en la Formación Soebi Blanco, Bonaire, Antillas Holandesas.

La Formación Soebi Blanco del Paleoceno en la isla de Bonaire, en el sureste del Caribe, ha atraído la atención de los geólogos desde 1931, cuando P. J. Pijpers describió la amplia gama de “rocas extrañas" en capas de conglomerado. El interés se vio impulsado en 1986 con la datación de un clasto granulítico resultando en una edad grenvilliana (ca. 1150 Ma, U-Pb, zircón), permitiendo a los autores interpretar una traslación de al menos 300 km hacia el este para la isla de Bonaire. Nuevos análisis petrográficos de 21 clastos dieron como resultado un amplio abanico de tipos de rocas, como metatrondhjemita, granofel?, metadiabasa, lava andesítica y toba, metasedimentaria epiclástica y metapsamita, mármol ultramilonítico, cuarzo arenita, arenisca conglomerática y calizas (wackstone, packstone). La variedad de tipos de roca apoya la idea de una región fuente combinada arco-continental, una condición que se cumplió en la esquina noroccidental de América del Sur durante el Paleoceno.

Palabras claves: Conglomerado, clastos exóticos, Paleoceno, Eocene.

INTRODUCTION

In 1930, Professor Louis Martin Robert Rutten (1884-1946) of the Utrecht University started a geological-biological research project in the Dutch islands of Aruba, Curaçao, Bonaire (THALMANN 1947) and the islands of Northern Venezuela (MARTÍNEZ 1992: 18). The team included Paul J. Pijpers and J. H. Westermann who carried out their doctoral theses on the geology of Bonaire and Aruba, respectively. One of the interesting findings in Bonaire was the Soebi Blanco conglomerate, which required an explanation for the origin of the “foreign pebbles” contained therein.

After work in Bonaire, Rutten`s team visited Venezuela with the sponsorship of Royal Dutch/Shell Group. The main reasons for this visit was to study igneous and metamorphic rocks of northern Venezuela to shed light on the origin of the foreign pebbles found in Bonaire. In the central states they surveyed the roads from Puerto Cabello to Valencia, and from La Guaira to Caracas in the Cordillera de la Costa (CdlC) (Fig. 1). They found that only rocks from the first section resembled some of those found in the Soebi Blanco conglomerate (RUTTEN 1931). P. J. Pijpers published three papers in which the “foreign pebbles” are highlighted (PIJPERS 1931a,b, 1933: 33-38).

With the exception of some volcanic rocks, the pebbles found in the Soebi Blanco Formation are not exposed in the Aruba-Bonaire-Curaçao (ABC) islands, as pointed out in the early work of RUTTEN (1931) through to the most recent work of WRIGHT & WILD (2011), so they must have been transported from elsewhere suggesting an allochtonous origin, an interpretation that has been extrapolated to the whole tectonic block of Bonaire island (e.g. PRIEM *et al*. 1986).

This work presents a petrographic characterization of a collection of pebbles from the Soebi Blanco Formation made in order to compare with other geological units of northern South America. The results may help to constrain the knowledge on the position of the Bonaire during Paleocene time.

THE SOEBI BLANCO FORMATION AND CARIBBEAN PLATE TECTONICS

The "Soebi Blanco Conglomerate" unit was formally introduced by PIJPERS (1933) with the type locality situated at 4.5 km north of Kralendijt on the main road to Rincón (Figs. 1 and 2). The unit was further studied by WESTERMANN & ZONNEVELD (1956) and BEETS *et al.* (1977) who raised it to formation status. SENN (1940: p. 1568) suggested a correlation of the turbiditic Scotland Formation (Barbados) and the Midden-Curaçao Formation (Curaçao) with the Soebi Blanco Conglomerate, which is in accordance with the temporal equivalence also pointed out by BEETS *et al.* (1977) and WRIGHT & WILD (2011).

The pre-Cenozoic rocks on Bonaire appear in two separate massifs, the northern formed by volcanic, plutonic and sedimentary rocks of Cretaceous age assigned to the Washikemba and Matijs groups (WRIGHT & WILD 2011), and a central massif only with volcanic rocks of the Washikemba Group (THOMPSON 2002).

The Soebi Blanco Formation crops out in the northwesternmost part of the central massif in the southeast side of the Ceru Largu. The Formation overlies unconformably the Washikemba Group and it is unconformably overlain by Eocene carbonate rocks (Fig. 3). Its thickness has been estimated at 400 m, and it consists of poorly consolidated fluviatile conglomerate, sandstone and shale. The clasts include felsic gneiss, schist, and quartzite, and also volcanic rocks probably from the underling Washikemba Group (PIJPERS 1931ab, 1933, BEETS *et al.* 1977). Its age is constrained by incorporated limestone clasts of Campanian ‐ Maastrichtian age (maximum) and the overlying Eocene carbonates unit (minimum), so it is generally considered to be Paleocene (BEETS *et al.* 1977).

PIJPERS (1933) described the pebbles of the conglomerate as rounded and usually not bigger that 12 cm (see Fig. 4) with carbonate cement, the fine grained rocks are identified as carbonate sandstone. The general strike of the strata is E-W and it dips gently to the north. The fluvial nature of the conglomerate and the centimeter-sized pebbles indicate a nearby source of the deposits and imply topographic relief sufficient to allow rapid transportation (PIJPERS 1933, PRIEM *et al.* 1986). Due to the erosion of the Soebi Blanco Formation the pebbles are also incorporated in the younger rocks and sediments surrounding the type locality, as mapped by PIJPERS (1933: 34). They also occur in the Late Cretaceous Rincón Formation but have much lower percentage, smaller size and less variety of rock types than in Soebi Blanco.

The Soebi Blanco Formation gained renewed interest in the work of PRIEM *et al.* (1986) who dated a “granulitic pebble” by Isotope Dilution - Thermal Ionization Mass Spectrometry (U/Pb, zircon, ID-TIMS). Seven sieve fractions were analyzed and the data define a discordia with intercepts at 1153 Ma (+28, -23) and 583 Ma (+90, -93). These authors placed Bonaire in a relevant context of Caribbean plate tectonics since the clasts were interpreted to possibly derive from the basement of today's Guajira-Santa Marta regions of Colombia and subsequently move about 300 km eastward. This interpretation has been widely accepted (e.g., EVA *et al.* 1989; WRIGHT & WILD 2011). Previously, MUESSIG (1984) proposed that in the Paleocene the ABC islands could have been located adjacent to Paraguaná suggesting it could have been the source of the Soebi Blanco “foreign pebbles”. However, this view was dismissed by PRIEM *et al.* (1986) due to the lack of geochronological data available at that time with the exception of a single U-Pb zircon age of ca. 1200 Ma in a gneiss of the Guajira Peninsula (IRVING 1971).

WRIGHT & WILD (2011) summarize that "*Within available age constraints the Soebi Blanco Formation may be temporally equivalent to the Danian Midden-Curaçao Formation on Curaçao, which also contains abundant continentally derived detritus. We speculate that the Soebi Blanco Formation may represent a fluvial facies of the Midden-Curaçao Formation, and that Bonaire was situated in proximity to Curaçao by the earliest Paleocene… The presence of coarse fluvial continental detritus in the Soebi Blanco Formation indicates that Bonaire became attached to continental South America by the latest Cretaceous / early Paleogene*." The authors dated detrital zircons using U-Pb LA-ICP-MS geochronology from turbidite units of Curaçao (Midden-Curaçao and Lagoen formations). The ages range from 64.4±3.8 Ma to 2684.9±16.8 Ma (n=151), with a major peak of Cretaceous age, but also minor highs of Triassic, Paleozoic and Neoproterozoic ages, including the age range of the Grenvillian orogeny. The authors conclude that the “*geochronological results are consistent with a dual provenance, one from the continental margin of South America, as exhibited by Triassic, Paleozoic and Neoproterozoic grains, and another from a Cretaceous arc. The intimate mixing of arc and continental detritus indicates a combined arc and continental source region. We suggest that the detritus was derived from the ca. 75 Ma collision zone between an arc terrane constructed on the Caribbean-Colombian Oceanic Plateau and the Ecuadorian/Colombian continental margin of South America*.” Based on this model and the possible correlation of the Soebi Blanco Formation and the turbidite units of Curaçao (SENN 1940, BEETS *et al.* 1977), the exotic clasts found in the Soebi Blanco conglomerate beds probably represent an assortment of rock types from those two amalgamated arc and continental provinces.

PETROGRAPHY

Previous petrography

Table 1 shows a summary of the petrography of the foreign pebbles in the Soebi Blanco Formation done by PIJPERS (1933: 35-36).

BEETS *et al*. (1977: 28, 36-37) describe the pebbles as "*Gneissose granoblastites mainly consisting of perthitic microcline, plagioclase (occasionally antiperthitic) and quartz, form the majority of the exotic pebbles... The rocks have flaser texture with quartz in lenses or ribbons. Relicts of garnet armoured by chlorite have been found in some of these pebbles. In one, sillimanite occurs. Diagnostic mineral assemblages of the hypersthene zone, however, have not been found. In addition to these, pebbles of quartzites, schists, and sandstones occur. Large cobbles and boulders of an algal limestone were found in all outcrops of the Formation. Pebbles of volcanic rocks, probably for a large part derived from the Washikemba Formation, forms the majority of the detritus.*" Also in a more general way they continue "*The rocks have flaser texture with quartz in lenses or ribbons, which give them a typical granulitic appearance. No diagnostic mineral assemblage of the hypersthene zone has been observed, however. Some pebbles contain relicts of garnet armored by chlorite.*" The authors also state that similar materials have been found in the turbidites of Early Paleocene age Midden-Curaçao Formation on the neighboring island of Curaçao. The individual pebble that was dated (sample Ant163, U-Pb, zircon, ID-TIMS, upper intercept age ca. 1150 Ma) was described "*with an unusually high zircon content. The pebble had a weight of 476 grams and a diameter of approximately 7 cm. Its main components are quartz, forming flattened lenticels with undulatory extinction and numerous inclusions of rutile needles, perthitic potassium feldspar (mainly microcline) and oligoclase (strongly sericitized and saussuritized, and with rims of secondary albite). Other constituents are biotite (strongly chloritized), chlorite, ilmenite (with rims of titanite), titanite, zircon and epidote minerals. The gneissose appearance of the rock is due to the streaky elongation of quartz grains and crystals of titanite, ilmenite and zircon. A thin (approximately 150 µm wide) veinlet of clinozoisite follows the same direction.*" This sole petrographic description does not warrant the use of the "granulitic" qualifier as an expression of high grade metamorphism.

The previous description matches with that of gneisses from the central part of the Paraguaná Peninsula and also in the northern half of the Venezuelan Cordillera de la Costa (Fig. 1) displaying regional metamorphism not higher than epidote-amphibolite or amphibolite facies (URBANI 2002).

Studied samples

From site locations 1 and 2 (Fig. 3) a total of 40 pebbles were collected. All well rounded and with a diameter ranging from 4 and 10 cm. They were cleaned to better appreciate their mineralogy and textures, after this a total of 21 pebbles were selected as representative of the range of rock types. There are also abundant milky quartz clasts which were not analyzed.

The sampled outcrops (Fig. 4) show poorly consolidated polymictic paraconglomerate (matrix supported), where the gravel sized clasts are partially rounded and poorly sorted indicating some textural maturity. The gravel was initially transported to a shoreline, and rounded by wave action, which in turn seems to explain the presence of some carbonate cement, as pointed out by PIJPERS (1933). The sedimentary environment was probably that of an alluvial fan with a relatively short course, originated in an area with abrupt relief but close to the shore. The centimetric size gravel was transported by a viscous debris flow to the final deposition site and the examined outcrops could represent the middle section of the alluvial fan.

The petrographic description from the thin sections follows and a full atlas with photomicrographs of all samples can be found at following URL address???

Metaplutonics

Bn-4. Metatrondhjemitic breccia. It is constituted of large (0.5-0.7 mm) and fractured plagioclase, and strongly undulatory quartz porphyroclasts. The matrix is made of the same minerals, but strongly ground with a grain size 20-30 times smaller than the porphyroclasts, and it is stained with iron oxides. The rock is crossed by quartz veins.

Bn-10. Proto-mylonitic metatrondhjemite. This sample is strongly cataclastic and crossed by trails of microgranular quartz. It consists of: 62% plagioclase (An18), subhedral, with Carslbad-Albite and Albite-Pericline twin laws with deformed lamellae, and sometimes undulatory extinction, slightly altered to sericite; 32% quartz has strongly sutured borders, it is abundant in the cataclastic matrix and also found as uncommon large grains with mortar texture; 6% alkali feldspar: microcline with irregular and deformed tartan twinning, slightly altered to sericite; <1% muscovite: partly primary and interstitial, but mostly sericite as alteration of feldspars; <1% mafics: scarce, and totally altered to epidote and chlorite (former biotite?). A = 6, P = 62, Q = 32, color index (C.I.): < 1%.

Bn-12. Protomylonitic metatrondhjemite. This sample is very similar to Bn-10, having a very fine grained quartz matrix with sutured borders visible in the larger grains. It has more epidote than the former. A = 0, P = 65, Q = 33, C.I. = 2%.

Bn-21. Proto-mylonitic metatrondhjemite. This sample shows some incipient cataclastic texture, having 81% of twinned and strongly sericitized plagioclase, 19% quartz in scarce large grains with mortar texture and in microgranular trains crossing the rock; <1% amphibole. The rock has stains of iron oxides and displays and traces of opaque minerals. A = 0, P = 81, Q = 19, C.I. <1%.

Feldspar-quartz gneisses

Bn-18. Epidote-alkali-feldspar-quartz protomylonictic gneiss (metaquartz-syenite). Essential minerals are perthitic microcline, quartz and epidote. Abundant and large twinned pleochroic brown titanite crystals and scarce clinopyroxene strongly altered to granular epidote and chlorite. Many very fine quartz grains are distributed in trails evidencing strong cataclasis, there are also epidote veins crossing the rock.

Bn-19. Chlorite-microcline-plagioclase-quartz gneiss (metaquartz-monzonite). The microcline is perthitic and there are choritized pseudomorphs that probably were clinopyroxenes. Large zircon crystals are present.

Metahypoabyssal

Bn-3. Metadiabase with blastophitic texture. It consists of 27% calcic plagioclase in lath-like twinned crystals replaced to epidote, some laths form radial aggregates; 72% xenoblastic clinopyroxene appears altered to actinolite, epidote and chlorite, associated with cuneiform titanite/leucoxene, which suggests a previous Ti-rich clinopyroxene, and 1% granular quartz. The actinolite displays a weak green pleochroism and radial-acicular habit, epidote is also slightly pleochroic and has a granular habit, and chlorite is pleochroic in green tones. There is scarce interstitial granular quartz.

Metavolcanics

Bn-11. Porphyritic andesite. Phenocrysts: 32% plagioclase with discontinuous zonation, sericitized and also carbonatized; 6% hornblende with light green color rhombic basal, sections which suggest a Mg-rich variety, altered to chlorite and opaque minerals. Matrix (62%) is devitrified somewhat siliceous and with abundant granular quartz, scarce mafic minerals and granular plagioclase that does not seem to be the product of devitrification.

Bn-14. Andesitic vitreous tuff (almost vitrophyre). It has a few fractured crystals of plagioclase and volcanic quartz. Plagioclase is twinned according to various laws, quartz has fractured borders, embayments, and vacuoles. The matrix is strongly choritized and shows perlitic or variolitic texture.

Bn-15. Andesitic vitreous tuff. Large fractured crystals of twinned and sericitized plagioclase, some augitic clinopyroxene altered to epidote and actinolite in its borders. The matrix contains quartz, altered plagioclase, granular epidote, and radial-acicular prehnite.

Bn-16. Andesitic crystal-vitreous tuff. Large fractured crystals of concentrically zoned, slightly sericitized, and altered to large granular epidote in its central parts. Epidotized pseudomorphs probably from former clinopyroxene. Hypocrystalline devitrified matrix rich in quartz and plagioclase, with traces of mafic material. Irregular epidote veins cross cut the sample.

Bn-17. Porphyritic andesitic lava. Plagioclase with oscillatory zoning. Slightly chloritized light green hornblende with rhombic basal sections. Hypocrystalline matrix of the same minerals, it probably was partially vitreous but it’s now devitrified and quartz and plagioclase rich.

Metatuff / epiclastic

Bn-5 and Bn-7. The samples are fragmented and altered. It consists of: 35% megacrysts (2-3 mm) of highly sericitized and argillized complexly twinned and fractured plagioclase crystals; 15% of chlorite and prehnite interpreted as former mafic minerals (probable clinopyroxene or amphibole). The matrix (50%) contains abundant angular quartz, plagioclase and chlorite probably from the devitrification of mafic glass. It could have been an andesitic tuff or some kind of epiclastic sediment.

Bn-14. Probably a siltstone with fragments of volcanic plagioclase and quartz. Some chloritized and oxidized mafic minerals.

Bn-15. Probably an epiclastic metasedimentary or intermediate to mafic tuff.

Metapsammite

Bn-9. This sample is probably a fine grained cataclastic quartzite. Porphyroclastic quartz has marked undulose extinction, there are also a few crystals of alkali feldspar. Chlorite (5%) has replaced a former mafic mineral, probably garnet due to the rough hexagonal cross section. The cataclastic matrix is well foliated and it is composed of very fine grained quartz, with fewer amounts of sericite and iron oxide. There are also rounded ("soccer ball") zircon crystals. The rock is cross-cut with abundant thin quartz veins.

Metacarbonate

Bn-8. Ultramylonitic marble. The sample consists of a strongly sheared cataclastic carbonate matrix, with some deformed and elongated porphyroclasts of a former mafic mineral (pyroxene?) completely choritized and also partly replaced by carbonate.

Siliciclastic rocks

Bn-1. Quartz arenite. It is constituted of 95% monocrystalline quartz with undulatory extinction and sutured borders; 2% poly-crystalline quartz and chert; 3% kaolinitized feldspar, with traces of detrital muscovite, tourmaline (with green pleochroism), titanite, zircon, and opaque minerals. This rock is interpreted to have been formed under conditions of advanced diagenesis, displaying quartz with sutured contacts and kaolinite cement.

Bn-2. Conglomeratic sandstone. This sample contains: a total of 20% clasts, and 65% matrix. The clasts are made of large (0.3-1 cm) mono- and polycrystalline quartz, chert, mafic-rich metalava rocks and fossil fragments all cemented by calcite (15%). The sandy matrix contains mono- and polycrystalline quartz, chert, andesitic and basaltic metalava fragments, twinned plagioclase, perthitic and argillized alkali feldspar, epidote, titanite, and fragments of phyllitic rocks. Veinlets of iron oxides cross-cut the rock.

Bn-6. Quartz-arenite. This sample mainly contains monocrystalline quartz (94%) with strong undulatory extinction, sutured, wavy, and straight borders. The remaining 5% of the rock is composed of chert, traces of feldspar, zircon with diverse morphologies, green pleochroic tourmaline, and opaque minerals. In this sample a pseudomatrix made of phyllitic rocks and micas is also present. This rock is interpreted to have been formed under conditions of low-grade diagenetic processes.

Carbonates

Bn-20. Fossiliferous limestone (mudstone). Although the fossil content in this rock is poorly preserved due to sparite recrystallization, there are still visible foraminifera showing their chambers. It is interpreted to have been deposited in deep-water environments.

Bn-22. Fossiliferous limestone (packstone). This sample has an abundant fossil content of coralline algae (red algae), gastropods, echinoderms and even a few planktonic foraminifera enclosed in a sparitic cement. The fossil content suggests a shallow to intermediate waters depth as to allow the reach of the foraminifera.

Similarities with rocks of Northwestern Venezuela

The several decades of additional study and mapping onshore western and central Venezuela since Rutten's 1930s survey allow us to make a number of inferences. For example, the metatrondhjemite samples display similarities with some of the rock types cropping out in Cocodite, central Paraguaná Peninsula (MENDI 2013) and in the Ávila Belt nearby Caracas.

Likewise, the feldspar-quartz gneisses resemble the granulite rocks of La Vela Bay basement as described by GRANDE & URBANI (2009) and GRANDE (2012), but strongly epidotized and chloritized. The sample dated by PRIEM *et al.* (1986) could have been similar to our Bn-19 that has many large zircon crystals.

The metadiabase with alkaline affinity probably comes from Caribbean Large Igneous Province exposures such as seen in Aruba, while the epiclastic and andesitic rocks suggest an intra-oceanic arc system origin.

The metapsammitic rock is similar to some inliers of garnet-feldspar-quartz gneiss of La Vela Bay granulite complex basement (GRANDE 2012) but highly altered. They contain "soccer ball" shaped zircons that are generally thought to signify a provenance from high-grade metamorphism at a deep crustal level (e.g. VAVRA *et al.* 1999)

The ultramylonitic marble is similar to that of El Guayabo Complex in the CdlC (GRANDE & URBANI 2009).

The sedimentary rocks are divided into:

1- Sandstones: One is a quartz-arenite with advanced diagenesis similar to the Early Cretaceous Aguardiente or Río Negro formations from the northwestern Venezuelan passive margin. Another sample of quartz-arenite with early diagenesis probably derives from a Paleogene unit. Such rock types today crop out around the Maracaibo Basin in Sierra de Perijá and the Mérida Andes.

2- Limestones: One is a red-algae rich packstone probably of Paleogene age, another sample is a mudstone that resembles levels in the Early Cretaceous Lisure Formation of the Cogollo Group of the Sierra de Perijá in western Venezuela near the border with Colombia.

DISCUSSIONS AND CONCLUSIONS

Early hypotheses on the source(s) of the "foreign pebbles" of Bonaire were advanced by RUTTEN (1931) and PIJPERS (1933). These authors suggested lithological similarities with rocks of the Puerto Cabello-Valencia region that belong to the CdlC in north-central Venezuela (Fig. 1), a large (~ 350 km) mountain chain that, as we know today, amalgamates at least 11 nappe terranes with different geological histories (URBANI 2012).

According to Pacific-derived evolution models for the Caribbean (e.g.: PINDELL *et al.* 2009: fig. 15; VAN DER LELIJ 2010: fig. 12; NEIL *et al.* 2011: fig. 10, and WRIGHT & WILD 2011: fig. 22d), during Paleocene-Early Eocene time Bonaire was attached to the northwestern corner of South America (Fig. 5A). At that same time most rock units that today are amalgamated in the CdlC were also situated in such paleogeographical location (URBANI 2012) and probably some of them were actively uplifting, subaerially exposed, and serving as source areas for the Soebi Blanco Formation. This can explain the lithological similarities of some of the "foreign pebbles" of Bonaire with units of northern Venezuela as pointed out by RUTTEN (1931), PIJPERS (1933) and this work.

Eventually, Bonaire along with the CdlC terranes were dispersed and variably accreted by the eastward movement of the leading edge of the Caribbean Plate (Fig. 5B). Some terranes were involved in the mid-Tertiary nappe-piling event in northern Venezuela CdlC, while others kept moving eastward as far as Margarita, Tobago and Barbados by means of the Miocene-Recent right-lateral fault systems acting on northern South America (PINDELL *et al*. 2005). The present geological setting of the CdlC was acquired during Late Oligocene-Early Miocene when the amalgamation process of the terranes was completed.

At the time of the PRIEM *et al.* (1986) work, the only Grenvillian age available for comparison purposes was that of IRVING (1971) from a gneiss of the Guajira Peninsula. More recently, GRANDE & URBANI (2009) described the petrography of surface and basement samples of high-grade metamorphic rocks from northwestern Venezuela considered of Grenvillian affinity. Such ideas have now been firmly established by new age determinations (U-Pb, zircon, LA-ICP-MS) by BAQUERO *et al.* (2011a,b) and BAQUERO (2013) from La Vela Bay basement complex, and MENDI (2013) from a previous unmapped unit in central Paraguaná. All such samples give similar ages ranging from old cores of 1.3-1.1 Ga to younger rims clustering at around 0.9 Ga probably representing an overprinted high-grade metamorphic phase or an unknown lead loss event. As previously suggested by MUESSIG (1984), this new information places the Paraguaná-Falcón terranes as players in the tectonics puzzle in relation with the Soebi Blanco Formation, especially if we consider that these were also eastwardly displaced from an original more westerly position. A granitic gneiss from the small Atuschon hill in Guajira Peninsula that is crossed by the Colombia-Venezuela border gave a Grenvillian concordant age of 1028.7±4.4 Ma (U-Pb, zircon, SHRIMP-II) (BAQUERO 2013).

The new petrography of 21 exotic pebbles from conglomerates of the Soebi Blanco Formation allow the interpretation that the clasts originated from a proximal source with a diversity of rock units exposed, as Cretaceous-Paleogene? marine sediments, quartz-rich metamorphic sources, mafic volcanics probably from either arc or plateau origin, felsic plutonics and high-grade metamorphics. This supports the provenance ideas synthesized by WRIGHT & WILD (2011) of a juxtaposed arc-continental source region, followed by a hecto-kilometer eastward displacement of Bonaire. Assuming a mid-Paleocene age (~60 Ma) for the Soebi Blanco Formation and using the Caribbean evolution models of PINDELL *et al*. (2005), a possible basin receiving sediments of a mixed arc and continental sources could have been in a position near todays Guajira, therefore its subsequent eastward translation may have been as high as 400-500 km, larger than the ~300 km proposed by PRIEM *et al.* (1986).

ZAPATA *et al.* (2010) worked on the provenance of the Oligocene Siamaná Formation conglomerates, Serranía de Jarara, Guajira, finding that granodiorites and porphyritic rocks are an important clast component. Moreover the ages of their detrital zircons (DZ) range from 51±1 to 2824±58 Ma. The younger age fits with the adjacent Eocene Parashi pluton (±50 Ma) of quartz-diorite to granodiorite composition with aplitic dikes. This Eocene age has also been determined in the basement of borehole PERLA-3X well, located in the Gulf of Venezuela (Fig. 1) at a central distance between the coastlines of the eastern Guajira and western Paraguaná peninsulas (BAQUERO 2013). In our own sampling of Soebi Blanco, no proper granodiorites were identified even though several varieties of aplitic granodiorites are pointed out by PIJPERS (1933: 35-36) (our Table 1). We suggest that any future recovery of granodioritic-aplitic rocks from Soebi Blanco Formation should be compared with rocks of the Eocene plutons of Guajira and Gulf of Venezuela, so a petrographic (and age) concordance potentially would provide a better constrain for the age of the Soebi Blanco Formation.

New U-Pb geochronological work of individual pebbles and of DZ from the sandstone beds of the Soebi Blanco Formation would be advisable to carry out, in order to compare with ages from the rapidly increasing U-Pb age database of Santa Marta and Guajira regions, to reconstruct paleogeography and to better assess the nature of the rock units exposed in the source region of the Soebi Blanco Formation sediments.

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Table 1. Clast rock types from the Soebi Blanco Formation.
Rock names and details summarized from PIJPERS (1933: 35-36).

Rock type	**Mineralogy and observations**
Granodiorites	
- Granodiorite aplite	Quartz, acid plagioclase, microcline microperthite and orthoclase, biotite, muscovite, magnetite, epidote, chlorite
- Plagiaplite	Aplitic rock, albite and oligoclase, few orthoclase and quartz and some ilmenite. Feldspar changes to sericite or epidote. Chlorite from previous ferromagnesian minerals. Resembles an albitite.
- Albiteaplite	Medium to coarse rock, quartz and acid plagioclase, frequent granophyric intergrowth. Secondary mineral: epidote, chlorite, calcite probably after hornblende?.
- Breccious aplite	Rock with quartz and plagioclase with distinct gneissose or breccious structure. High degree of cataclasis. Plagiclase strongly sericitized. Also biotite, magnetite, chlorite, epidote.
Gneisses	Medium to fine grained rocks. Feldspars (orthoclase, microcline, microperthite, microcline, albite-oligoclase also andesine) frequently altered to sericite and epidote. Quartz, biotite (generally chloritized). Small quantities of muscovite, pyroxene, amphibole, magnetite, ilmenita, pyrite, hematite, titanite, apatite, zircon. Cataclastic features. Some details follow:
- Microcline gneiss	Very leucocratic.
- Plagioclase gneisses	Some strongly cataclastic. Rich in sericite.
- Microcline plagioclase gneiss	Orthogneiss.
- Albite gneiss	
- Albite microcline gneiss	
- Breccious diorite gneiss	Very few quartz crystals.
Zoisite quartz feldspar schist	Quartz, acid plagioclase, muscovite, chloritized biotite and zoisite. Mortar structure.
Quartzite	Quartz, acid plagioclase, biotite, sericite, ore, chlorite, calcite.
Graywacke quartzite	Quartz, acid plagioclase, microperthite and sericite. Minor amounts of ore, zircon, apatite and chert inclusion.
Quartz epidote rock	Strongly altered rock with epidote and quartz.
Polygeneous conglomerate	In a graywacke like matrix there occur small pebbles of quartz, chert and plagioclase gneiss.
Silicified mica bearing shale	The author compares this rock with the Midden Curaçao Formation.
Amphibolite	"Similar rocks have been found in Aruba"
Uralite diabase porphyrite	Very fine grained with strong uralitization. Some pyroxenes have been preserved.

FIGURES

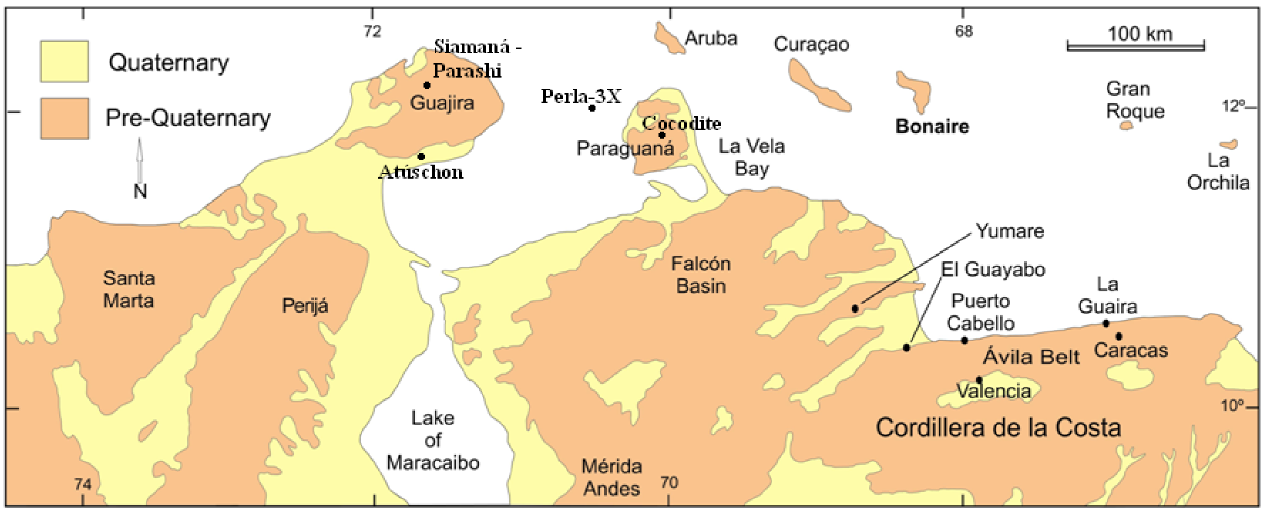

Fig. 1. General location map of Bonaire and other places cited in text.

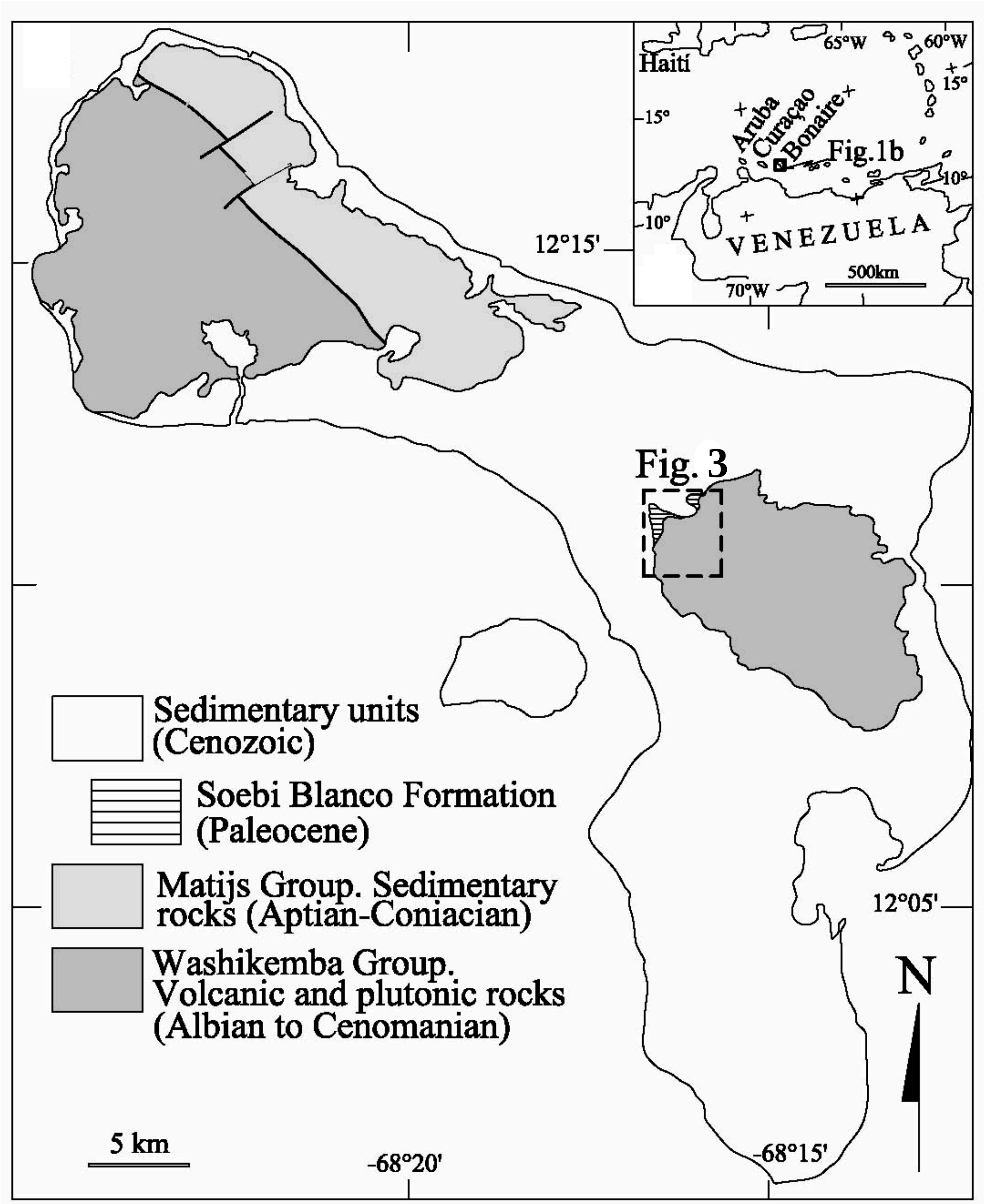

Fig. 2. Simplified geology of the island of Bonaire, showing the area of sample collection (our Fig. 3), after W*RIGHT* & W*ILD* *(2011).*

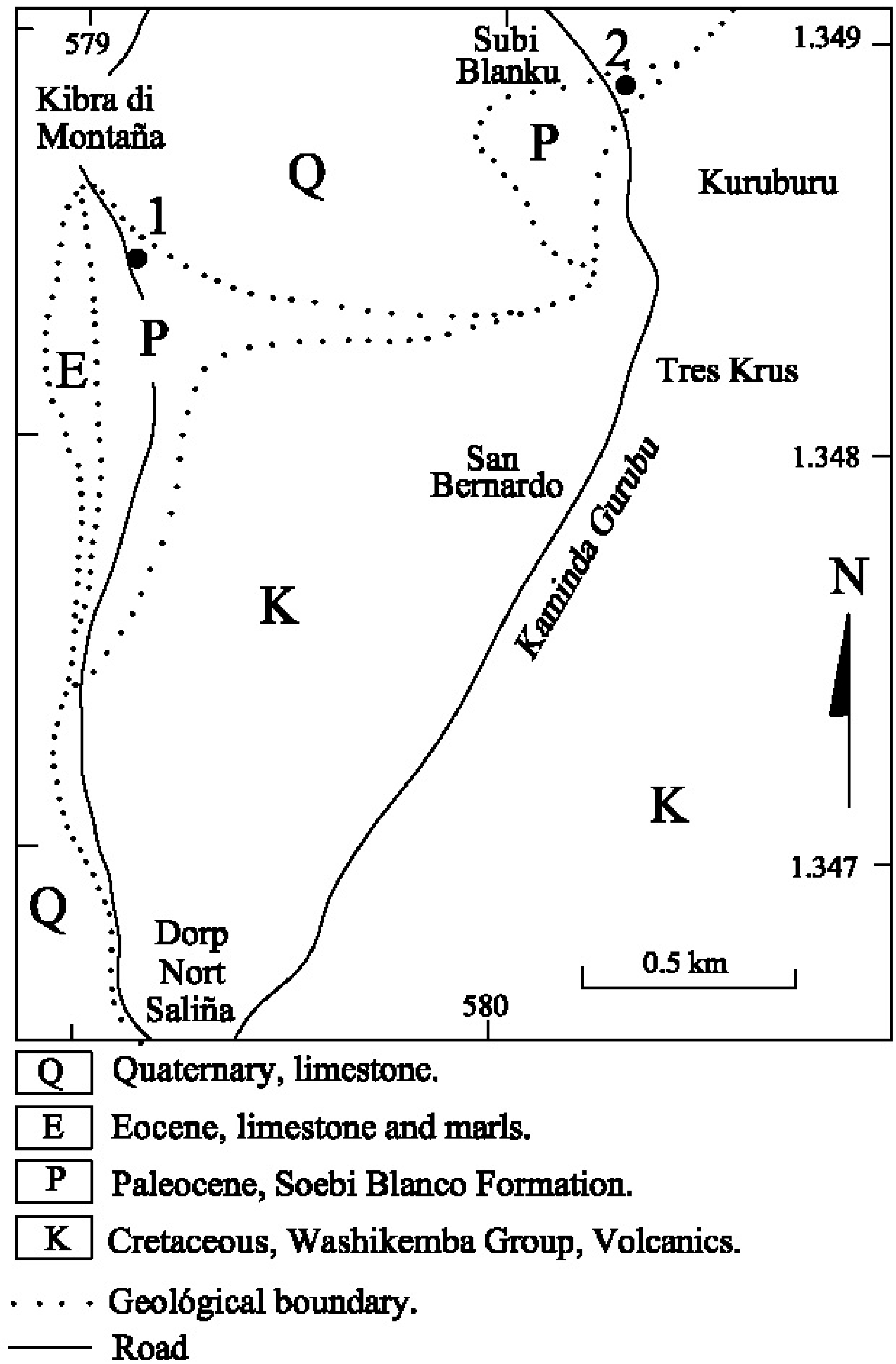

Fig. 3. Geological map of the Subi Blanku area. 1 and 2 locate the conglomerate samples collected in the Soebi Blanco Formation. Geology after PIJPERS *(1933, integrated in* WESTERMANN *&* ZONNEVELD *1956). Topographic base: Bonaire, sheet 4, 1:25 000, UTM coordinates zone N19. Cadastral Survey Department, Netherlands Antilles, 1982.*

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Fig. 4. Conglomerate outcrop of the Soebi Blanco Formation (locality 1 of Fig. 3). Scale: 35 cm long hammer

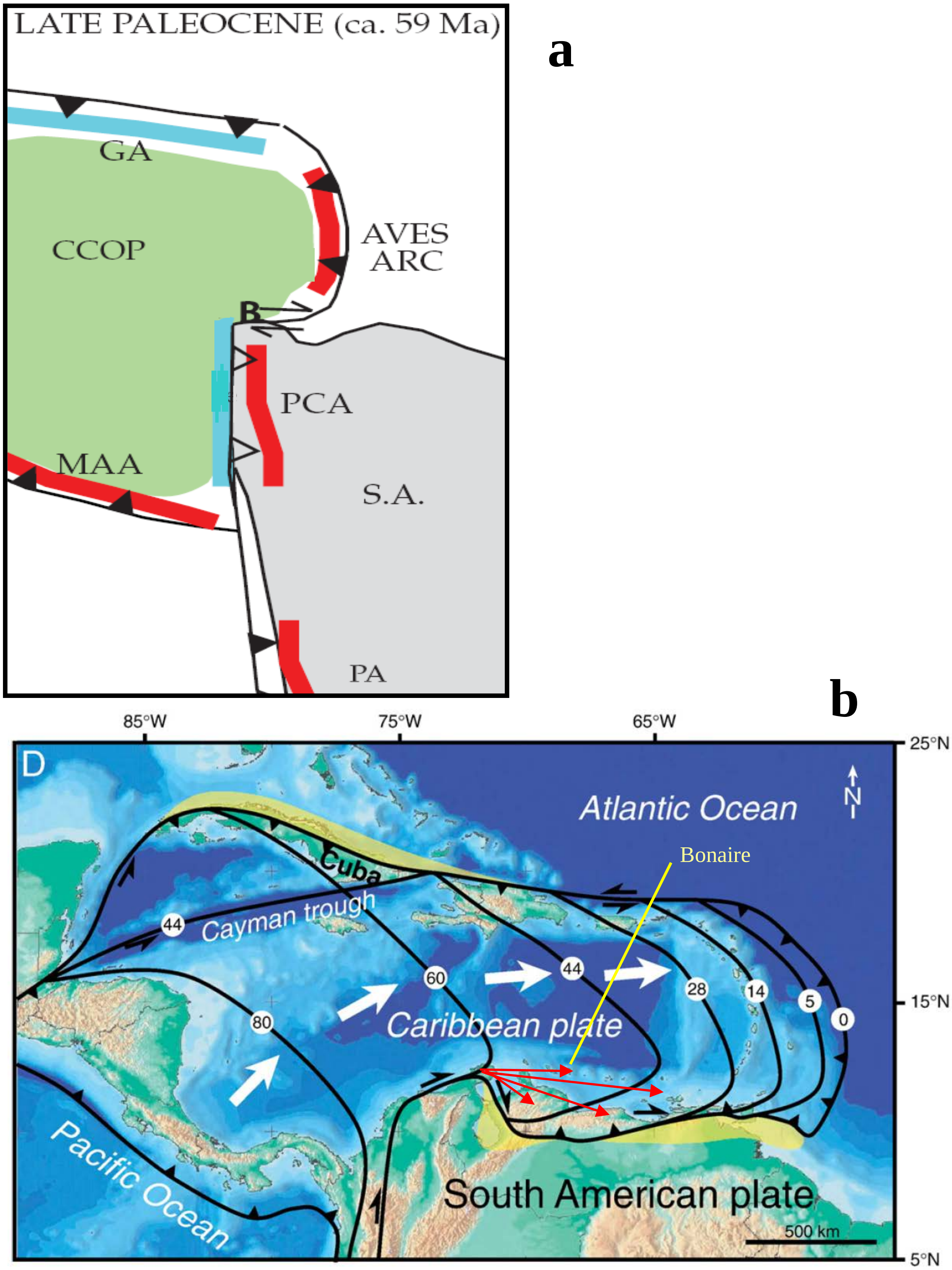

Fig. 5. a. Hypothetical position of Bonaire (B) during Paleocene times that allowed drainage from mixed arc-continental sources to feed the Soebi Blanco Formation (after WRIGHT & WILD *2011).* ***b****. Several rock units originally juxtaposed in Paleocene times in the northwestern corner of South America were later distributed and emplaced (red arrows) into the wide deformation belt of the Caribbean - South American plates (base figure from* XIE et al. *2010, in turn based on* PINDELL et al. *2005).*