

Precambrian rocks in an Early Tertiary conglomerate on Bonaire, Netherlands Antilles (southern Caribbean borderland): evidence for a 300 km eastward displacement relative to the South American mainland?

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Received 20 December 1985; accepted in revised form 20 January 1986

Abstract

A U-Pb analysis of seven zircon fractions from a granulitic pebble in the Late Paleocene and/or Eocene fluviatile Soebi Blanco conglomerate on Bonaire, Netherlands Antilles (southern Caribbean borderland) indicates that the rock has been derived from a Precambrian basement with an age of approximately 1150 Ma. Such basement rocks do not occur on Bonaire. The nature of the conglomerate testifies to derivation from a nearby topographic high. It is suggested that the source area was located in the Guajira area, implying an eastward migration of Bonaire of some 300 km relative to the South American mainland since the beginning of the Tertiary.

Introduction

Bonaire forms part of the island chain of the Leeward Netherlands Antilles (Fig. 1), probably the remnants of an island arc that collided with the South American continental margin in the Coniacian/Campanian interval (Beets et al. 1984). The volcanic core of Bonaire is made up of the Washikemba Formation (Pijpers 1933), an over 5000 m thick, predominantly submarine island arc succession of dacitic-rhyolitic and basaltic-andesitic composition (bimodal distribution, Beets et al. 1984). Most of the Washikemba Formation consists of submarine lavas, shallow intrusions and subaqueous pyroclastic flows alternating with pelagic sediments and, in the upper part of the Formation, volcanoclastic sandstones and boulder beds (Pijpers 1933; Beets et al. 1977a, 1977b, 1984). Fossil evidence (Beets et al. 1977b; Smit 1977) and K-Ar hornblende dates from a volcanic tuff bed (Priem et al. 1979) point to a Late Albian through Turonian/

Coniacian age for the Formation. Emergence of the volcanic core took place toward the Turonian/Coniacian, as evidenced by the appearance of boulder beds and conglomerates. The whole Washikemba Formation shows evidence of low-grade metamorphism (zeolite and pumpellyite-prehnite facies). On the basis of K-Ar and Rb-Sr data, Priem et al. (1979) suggested that (at least) two phases of increased ambient temperature have affected the Formation, about 78 Ma ago (Campanian) and about 61 Ma ago (Early Paleocene). The Formation has been tilted, but no large-scale structures have developed.

The Washikemba Formation is unconformably overlain at a few places by Middle and Late Maastrichtian limestones, marls and calcareous sandstones (Beets et al. 1977b; MacGillavry & Beets 1977). Next in the succession follows an up to 400 m thick sequence of fluviatile conglomerates, sandstones and shales (mudstones) of Late Paleocene and/or Eocene age, the Soebi Blanco Formation,

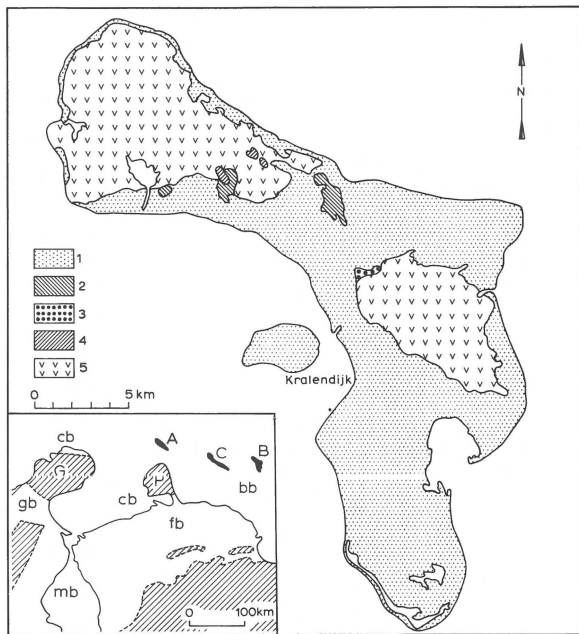


Fig. 1. Simplified geological sketch map of Bonaire (after Beets et al. 1977b). Legend: 1, Quaternary and Neogene limestones; 2, Eocene limestones and marls; 3, Eocene and/or Late Paleocene fluvial conglomerates, sandstones and shales (Soebi Blanco Formation); 4, middle and late Maastrichtian limestones and marls; 5, Washikemba Formation, the volcanic core of the island. The inset shows the present position of the Leeward islands of the Netherlands Antilles, marginal to northern South America: A, Aruba, C, Curaçao and B, Bonaire. The northern South American borderland has been a zone of subsidence and sedimentation since the beginning of the Tertiary, leading to basins filled with Tertiary strata (bb, Bonaire Basin; fb, Falcón Basin; mb, Maracaibo Basin; cb, Chichibacoa-Golfo de Venezuela Basin; gb, Baja Guajira Basin), except for the topographic highs of Paraganá (P, basement of metamorphic Paleozoic and Mesozoic rocks) and Guajira (G, basement of metamorphic Precambrian and Paleozoic rocks) (after Case et al. 1984). The hatched areas on the mainland represent pre-Tertiary terrains (undifferentiated metamorphic and/or folded Mesozoic and/or older rocks).

which in turn is overlain by limestones and marls of Eocene age (Beets et al. 1977b). From the Early Miocene onward the island shows a slow, discontinuous emersion, leading to the development of elevated terraces of coral reefs and emerged reef talus (De Buissonjé 1974; Herweijer et al. 1977).

Soebi Blanco conglomerate

The conglomerates of the Early Tertiary Soebi Blanco Formation contain a large proportion of exotic cobbles and pebbles in addition to material derived from the Washikemba Formation (Pijpers 1933; Beets et al. 1977b). Most of the exotics are leucocratic gneisses and granulitic rocks, with minor amounts of quartzites, schists and amphibolites. All these rocks do not occur in situ on Bonaire, nor anywhere else on the island chain of the Netherlands' and Venezuelan Antilles, so they must have been transported from elsewhere. Nevertheless, the fluvial nature of the conglomerates and its coarse debris-size indicate a nearby source of the deposits and imply topographic relief sufficient to permit rapid transportation of detritus by fast-flowing water. It is not possible to determine the direction of transportation of the stream-laid deposits.

The main exposure of the Soebi Blanco Formation is in central Bonaire some 4.5 km north of Kralendijk, along the main road to Rincon (Fig. 1). At this location the Formation consists of a northward dipping sequence of conglomerates, sandstones and shales. The majority of the exotic pebbles is gneissose granoblastic rocks mainly composed of perthitic potassium feldspar, plagioclase (occasionally antiperthitic) and quartz (Pijpers 1933; Beets et al. 1977b). The rocks have a 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 armoured by chlorite.

Isotopic age studies have been made on a number of granulitic pebbles, to obtain information about their source region.

Rb-Sr whole-rock study

Rb-Sr analyses were made on four granulitic pebbles. Rb and Sr contents and Rb/Sr ratios were measured on pressed-powder pellets by X-ray fluorescence spectrometry, using a Philips PW 1450/AHP automatic spectrometer. Mass-absorption

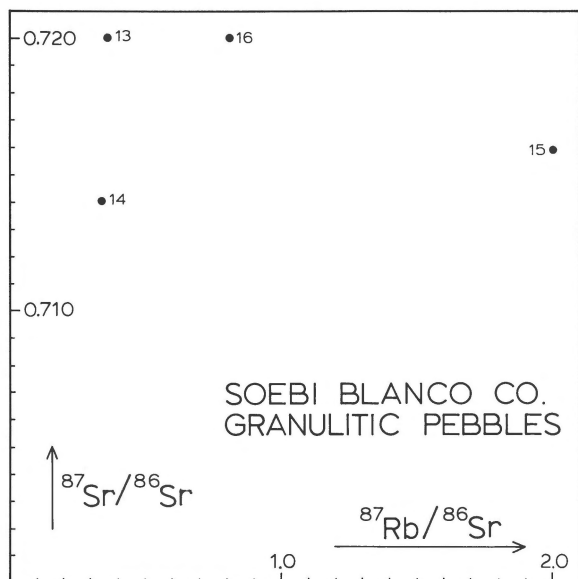


Fig. 2. Plot of Rb-Sr whole-rock data. The numbers refer to the samples in Table 1.

correction for both sample and external standard are based upon the Compton scattering of the MoK α primary beam (Verdurmen 1977). The strontium isotope analyses were made directly on unspiked strontium, using a computer-controlled Varian CH5 mass-spectrometer with Faraday cage collector and digital output. The analytical accuracy is believed to be within 1% for Rb/Sr and 0.05% for $^{87}\text{Sr}/^{86}\text{Sr}$.

The results are listed in Table 1 and plotted in Fig. 2. No linear relationship is produced by the data-points, but this can hardly be expected in the case of a suite of loose, stream-laid pebbles. The Rb-Sr systems do testify, however, to the presence of 'old' radiogenic Sr and a prolonged Rb-Sr history. For three samples (ANT 13, 14, 16) a Pre-

cambrian history is apparent, if a conventional initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of approximately 0.705 is assumed.

U-Pb zircon age

One pebble was found (ANT 163) with an unusually high zircon content. The pebble had a weight of 476 gram and a diameter of approximately 7 cm. Its main components are quartz, forming flattened lenticles 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 sericitized), 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 $150\ \mu\text{m}$ wide) veinlet of clinozoisite follows the same direction.

The zircons are clear. Inclusions are scarce and internal zoning has not been detected. Most grains are rounded or oval-shaped, but subhedral prisms, occasionally with sharp terminations, do also occur. The size of the zircons is relatively large, the largest observed crystal being $650\ \mu\text{m}$ long. From the ground pebble 1852 mg of zircon has been recovered (approximately 0.4 Wt% of the total sample) by density separation using overflow centrifuges (IJlst, 1973) with, in succession, bromoform, di-iodomethane and Clerici solution, followed by magnetic separation with a modified Frantz isodynamic separator (Verschure & IJlst 1969). The zircon concentrate was sieved into size fractions

Table 1. Rb-Sr data granulitic pebbles (see Fig. 2)

Pebble Nr.	Rb (ppm)	Sr (ppm)	Rb/Sr (Wt/Wt)	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{87}\text{Rb}/^{86}\text{Sr}$
ANT 13	49.0	391	0.1254	0.72006	0.364
ANT 14	37.5	316	0.1186	0.71404	0.344
ANT 15	89.5	128	0.7037	0.71592	2.04
ANT 16	72.5	259	0.2804	0.72001	0.813

using specially designed sieves with oblong apertures in order to facilitate the passing of the elongated crystals. Chemical decomposition and separation of uranium and lead were essentially according to Krogh (1973), followed by purification of the lead by anodic deposition (Arden & Gale 1974). Uranium and lead contents were determined by isotope dilution. The isotope measurements were made on a computer-controlled Teledyne SS-1290 mass-spectrometer with Faraday cage collector and digital output. Lead was mounted as nitrate on a single zone-refined Re filament with silica gel and phosphoric acid, and measured according to Barnes et al. (1973). Uranium was loaded as nitrate on the two zone-refined Re side-filaments of a triple filament source (Shields 1966). All measured isotope ratios are corrected for mass fractionation factors of 0.15% per mass unit for uranium and 0.10% per mass unit for lead (heavy isotopes depleted relative to the lighter ones); these factors were obtained by analysing NBS uranium and lead standards under the same conditions as the samples. The laboratory procedure blanks for lead were approximately 0.3% (about 1 ng) of the total lead. The lead isotope ratios were corrected for procedure blanks assuming the 'average modern lead' (AML) composition (Stacey & Kramers 1975)

and for initial lead using a backward extrapolation from AML with $\mu = 9.74$ and $W = 36.84$. The analytical accuracy is believed to be within 1% for the uranium and lead contents, 0.5% for $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{208}\text{Pb}/^{206}\text{Pb}$, and 2.5% for $^{204}\text{Pb}/^{206}\text{Pb}$.

Seven sieve fractions of the zircon concentrate have been analyzed. The fractions, weights and analytical data are listed in Table 2. Fig. 3 shows a plot of the U-Pb data in a concordia diagram. The best-fit line through the data-points (MSWD = 0.5) defines a discordia with upper and lower intercepts at 1153^{+28}_{-23} Ma and 583^{+90}_{-93} Ma (1σ), respectively. No older radiogenic lead is apparent. The geochronological significance of the lower intercept is a matter of speculation, but the upper intercept can be taken as signalling the age of (re)crystallization of the zircons. It is not possible, on the basis of this isolated loose rock fragment, to assign confidently a unique geological interpretation to the upper intercept, but the absence of inclusions, the lack of zoning, the high degree of rounding together with the coarse grain size and the low uranium content suggest (re)crystallization of the zircons during the granulite-facies metamorphism. The 1153 Ma upper intercept may then be related to the age of the metamorphism.

Table 2. Zircon U-Pb data granulitic rock ANT 163 (see Fig. 3)*

Fraction (μm)	U ppm	Pb ppm	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{208}\text{Pb}}{^{206}\text{Pb}}$	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	Calculated ages (Ma)		
								$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$
1. > 130	86.2	15.8	6092	0.07865	0.12469	1.858	0.1765	1048	1066	1104
2. 110–130	85.9	15.9	10247	0.07811	0.12054	1.891	0.1788	1060	1078	1114
3. 90–110	85.5	15.7	7187	0.07843	0.12053	1.876	0.1779	1056	1073	1107
4. 60–90 NM	87.6	16.2	9125	0.07804	0.11765	1.890	0.1792	1063	1078	1108
5. 60–90 M	88.1	15.9	5090	0.07879	0.12979	1.809	0.1726	1027	1049	1095
6. 50–60	87.3	15.8	7931	0.07784	0.12376	1.837	0.1752	1041	1059	1096
7. < 30	86.2	15.4	4467	0.07888	0.12746	1.790	0.1715	1020	1042	1087

* Column 1: NM, non-magnetic; M, magnetic. Columns 2 and 3: procedure blanks (chemistry and loading) are less than 1% (1–2 ng) of the total lead and less than 0.02% (less than 0.3 ng) of the total uranium. Columns 4 through 7: measured lead isotope ratios. Columns 7 and 8: ratios radiogenic $^{207}\text{Pb}/^{235}\text{U}$ and radiogenic $^{206}\text{Pb}/^{238}\text{U}$, after correction for 'common lead'. The measured lead isotope ratios are first corrected for the procedure blanks by assuming that all contaminant lead has the 'Average Modern Lead' (AML) composition ($^{206}\text{Pb}/^{204}\text{Pb} = 18.70$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.628$ and $^{208}\text{Pb}/^{204}\text{Pb} = 38.63$; Stacey and Kramers, 1975). Then it is assumed that all remaining ^{204}Pb is a component of initial common lead, incorporated in the zircons during crystallization. The isotopic composition of this initial lead is approximated by a backward extrapolation from AML to the preliminary intercept age of the suite of zircons.

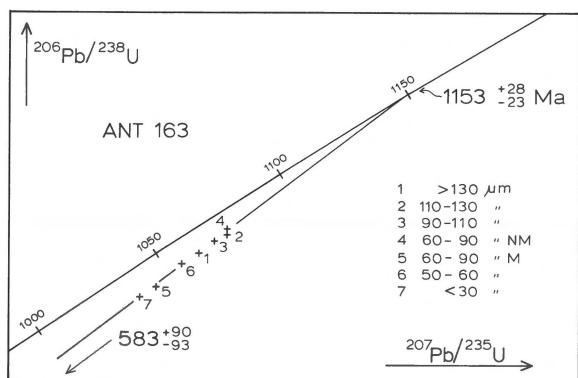


Fig. 3. Plot of U-Pb zircon data from sample ANT 163. The numbers refer to the fractions in Table 2.

Location of the source area and tectonic implications

The granulitic rocks in the Soebi Blanco conglomerate testify that in the Early Tertiary basement rocks with an age of approximately 1150 Ma formed a nearby source of high relief. In the present-day configuration Bonaire is separated from the Venezuelan mainland by the Bonaire trench with a depth of over 2000 m. The trench is a sedimentary basin filled with as much as 4000 m of Tertiary strata and forms the offshore continuation of the Tertiary Falcón basin on the mainland (Fig. 1), a zone of subsidence and sedimentation since the beginning of the Tertiary (Case et al. 1984; Muessig 1984). It seems unlikely that the topographic high of Precambrian basement from which the exotics in the Soebi Blanco conglomerate were derived could have been located in such a subsiding zone, the more so as xenoliths of metamorphic rocks in Oligocene-Miocene trachybasalts in the central Falcón basin indicate that this subsiding zone is underlain by Mesozoic rather than Precambrian basement (Muessig 1978; Feo-Codecido et al. 1984). Movements between the Caribbean and South American plates since the Early Tertiary have to be considered, however, when attempting to localize the provenance of the approximately 1150 Ma old Soebi Blanco rocks. Recognition of the source area could then set constraints on the magnitude of the displacement of Bonaire since the beginning of the Tertiary.

Current models of Caribbean tectonic evolution postulate that in the Eocene the southward movement of the Caribbean plate with respect to the South American plate changed to an eastward motion and remained easterly since then (e.g. Burke et al. 1984). The Netherlands' and Venezuelan Antillean islands have also been carried eastward, so the Soebi Blanco conglomerate has been acquired when Bonaire was situated west of its present position with respect to the South American mainland. The greater part of the South American borderland west of Bonaire was a zone of subsidence and sedimentation during the Tertiary, with two prominent topographic highs shedding sediments into the adjacent basins: the present Paraguaná and Guajira peninsulas (Fig. 1; Case et al. 1984). The exotics in the Soebi Blanco conglomerate could thus very well have been derived from one of these blocks. Muessig (1984) proposes a model for the tectonic evolution of the southern Caribbean borderland implying that at the beginning of the Tertiary the Netherlands' and Venezuelan Antillean islands formed a contiguous unit, with Bonaire and/or Curaçao located adjacent to the Paraguaná block. He suggests that this high could have been the source area of the Soebi Blanco exotics, which he relates to the Jurassic basement rocks on Paraguaná. This correlation is no longer tenable, however, in view of the Precambrian age established for the granulitic rock in the Soebi Blanco conglomerate (this paper) and the absence of Precambrian basement in the Paraguaná block (Case et al. 1984). On the other hand, a core of Precambrian basement does occur in the Guajira Peninsula (Irving 1971; Case et al. 1984). This basement consists of metamorphic rocks, including gneisses for which an isolated zircon age of approximately 1200 Ma has been reported (Irving 1971). Unfortunately, as far as we know, this is the only age determination presently available from the Guajira Precambrian basement.

Following Muessig's (1984) tectonic evolution model we consider it likely that the Guajira block, not the Paraguaná block, has been the source area of the exotic rocks in the Soebi Blanco conglomerate. This would imply that at the beginning of the Tertiary Bonaire was situated in the Guajira area

and has migrated since then some 300 km eastward relative to the South American mainland.

Acknowledgments

This work would not have been possible without the efforts of the entire staff of the Z.W.O. Laboratory of Isotope Geology, Amsterdam. The authors are particularly indebted to the staff members P.A.M. Andriessen, N.A.I.M. Boelrijk, E.H. Hebeda and R.H. Verschure for discussions and critical comments. E.H. Hebeda also supervised the mass-spectrometric analyses. This study forms part of the research programme of the 'Stichting voor Isotopen-Geologisch Onderzoek', supported by the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

References

- Arden, J.W. & N.H. Gale 1974 New electrochemical technique for the separation of lead at trace levels from natural silicates – *Anal. Chem.* 46: 2–9
- Barnes, L.L., T.J. Murphy, J.W. Gramlich & W.R. Shields 1973 – Lead separation by anodic deposition and isotope ratio mass-spectrometry of microgram and smaller samples – *Anal. Chem.* 45: 1881–1884
- Beets, D.J., H.J. MacGillavry & G.Th. Klaver 1977a Volcanic-sedimentary facies associations in the Washikemba Formation, Late Cretaceous, Bonaire – *Abstr. 8th Car. Geol. Conf. (Curaçao)*; 13–15
- Beets, D.J., H.J. MacGillavry & G.Th. Klaver 1977b Geology of the Cretaceous and Early Tertiary of Bonaire – 8th Car. Geol. Conf. (Curaçao), Guide to field excursions: 18–28
- Beets, D.J., W.V. Maresch, G.Th. Klaver, A. Mottana, R. Bocchio, F.F. Beunk & H.P. Monen 1984 Magmatic rock series and high-pressure metamorphism as constraints on the tectonic history of the southern Caribbean. In: W.E. Bonini, R.B. Hargraves & R. Shagan (eds) *The Caribbean-South American plate boundary and regional tectonics* – *Geol. Soc. America Memoir 162*: 95–130
- Burke, K., C. Cooper, J.F. Dewey, P. Mann & J.L. Pindell 1984 Caribbean tectonics and relative plate motions. In: W.E. Bonini, R.B. Hargraves & R. Shagan (eds) *The Caribbean-South American plate boundary and regional tectonics* – *Geol. Soc. America Memoir 162*: 31–63
- Case, J.E., T.L. Holcombe & R.G. Martin 1984 Map of geologic provinces in the Caribbean region. In: W.E. Bonini, R.B. Hargraves & R. Shagan (eds) *The Caribbean-South American plate boundary and regional tectonics* – *Geol. Soc. America Memoir 162*: 1–30
- De Buissonjé, P.H. 1974 Neogene and Quaternary geology of Aruba, Curaçao and Bonaire (Netherlands Antilles) – *Natuurwet. Studiekring Suriname Nederl. Antillen (Utrecht)* 78: 291 pp
- Feo-Codicedo, G., F.D. Smith, N. Aboud & E. de Di Giacomo 1984 Basement and Paleozoic rocks of the Venezuelan Llanos basins. In: W.E. Bonini, R.B. Hargraves & R. Shagan (eds) *The Caribbean-South American plate boundary and regional tectonics* – *Geol. Soc. America Memoir 162*: 175–187
- Herweijer, J.P., P.H. de Buissonjé & J.I.S. Zonneveld 1977 Neogene and Quaternary geology and geomorphology – 8th Car. Geol. Conf. (Curaçao) Guide to field excursions: 39–55
- IJlst, L. 1973 A laboratory overflow-centrifuge for heavy-liquid mineral separation – *Am. Mineral.* 58: 1088–1093
- Irving, E.M. 1971 La evolución estructural de los Andes mas septentrionales de Colombia – *Colombia Bol. Geol. IN-GEOMINAS 19/2*: 1–89
- Krogh, T.E. 1973 A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations – *Geochim. Cosmochim. Acta* 37: 483–494
- MacGillavry, H.J. & D.J. Beets 1977 The Rincon problem or how to confuse the geologist – *Abstr. 8th Car. Geol. Conf. (Curaçao)*: 103–105
- Muessig, K.W. 1978 The central Falcon igneous suite, Venezuela: alkaline basaltic intrusions of Oligocene-Miocene age. In: H.J. MacGillavry & D.J. Beets (eds) *The 8th Caribbean Geological Conference (Willemstad, Curaçao, 1977)* – *Geol. Mijnb.* 57: 261–266
- Muessig, K.W. 1984 Structure and Cenozoic tectonics of the Falcón Basin, Venezuela, and adjacent areas. In: W.E. Bonini, R.B. Hargraves & R. Shagan (eds) *The Caribbean-South American plate boundary and regional tectonics* – *Geol. Soc. America Memoir 162*: 217–230
- Pijpers, P.J. 1933 Geology and paleontology of Bonaire (D.W.I.) – Ph.D. thesis Utrecht State University: 103 pp
- Priem, H.N.A., P.A.M. Andriessen, D.J. Beets, N.A.I.M. Boelrijk, E.H. Hebeda, E.A.Th. Verdurmen & R.H. Verschure 1979 K-Ar and Rb-Sr dating in the Cretaceous island-arc succession of Bonaire, Netherlands Antilles – *Geol. Mijnb.* 58: 367–373
- Shields, W.R. 1966 Technical Note No. 227 U.S. National Bureau of Standards
- Smit, J. 1977 Planktonic foraminiferal faunas from the upper part of the Washikemba Formation, Bonaire – *Abstr. 8th Car. Geol. Conf. (Curaçao)*: 192–193
- Stacey, J.S. & J.D. Kramers 1975 Approximation of terrestrial lead isotope evolution by a two-stage model – *Earth Planet. Sci. Lett.* 26: 207–221
- Verdurmen, E.A.Th. 1977 Accuracy of X-ray fluorescence spectrometric determinations of Rb and Sr concentrations in rock samples – *X-ray Spectr.* 6: 117–122
- Verschure, R.H. & L. IJlst 1969 An asymmetrical vibrating unit for the Frantz magnetic separator – *Z.W.O. Laboratorium voor Isotopen-Geologie, Amsterdam, Reports on Investigations 1968/1969*: 90