GEOLOGIE EN MIJNBOUW© VOLUME 57 (2), p. 293-296 1978

Rb-Sr EVIDENCE FOR EPISODIC INTRUSION OF THE LATE CRETACEOUS TONALITIC BATHOLITH OF ARUBA, NETHERLANDS ANTILLES

H.N.A. PRIEM[1], D.J. BEETS[2], N.A.I.M. BOELRIJK[1], E.H. HEBEDA[1], E.A.Th. VERDURMEN[1] & R.H. VERSCHURE[1]

ABSTRACT

Priem, H. N. A., D. J. Beets, N. A. I. M. Boelrijk, E. H. Hebeda, E. A. Th. Verdurmen & R. H. Verschure (1978). Rb-Sr evidence for episodic intrusion of the Late Cretaceous tonalitic batholith of Aruba, Netherlands Antilles. *In:* H. J. Mac Gillavry & D. J. Beets (eds.): The 8th Caribbean Geological Conference (Willemstad, 1977). Geol. Mijnbouw, 57, p. 293-296.

Rb-Sr investigations revealed an age of 85.1 ± 0.5 Ma (Coniacian-Santonian) for the northwestern part of the tonalitic batholith on Aruba, and an age of 70.4 ± 2.0 Ma (Maastrichtian) for the remaining part. The dates are interpreted in terms of an episodic intrusion of the batholith. It is discussed that the two episodes of tonalitic magmatism belong to two different tectonic-magmatic phases in the geologic evolution of the Caribbean region.

INTRODUCTION

The greater part of the island of Aruba (Fig. 1) is occupied by a composite batholith of mainly tonalitic composition, intrusive into folded sequences of metavolcanics (predominantly of basaltic composition) and minor metasediments showing greenschist facies metamorphism and containing scarce ammonites of probably Turonian age. A wide variety of rocks can be recognized in the batholith. The most common rock is hornblende tonalite, occasionally rich in biotite, but other components include (quartz)norite, quartz-hornblende gabbro, trondjemite, granitic pegmatite and melatonalite (hooibergite). Wide-spread assimilation of basaltic country rock by the emplacing tonalitic magma has taken place (WESTERMANN, 1932; HELMERS, 1977; HELMERS & BEETS, 1977).

[1] Z.W.O. Laboratorium voor Isotopen-Geologie, De Boelelaan 1085, 1081 HV AMSTERDAM, The Netherlands.
[2] Geologisch Instituut, Universiteit van Amsterdam, Nieuwe Prinsengracht 130, 1018 VZ AMSTERDAM, The Netherlands.

Rb-Sr INVESTIGATIONS

This paper discusses the results of Rb-Sr investigations on eleven tonalitic samples from the batholith, collected all over the island (Fig. 1). Whole-rock measurements were made on all samples. From four samples biotite was separated and analysed. The results are listed in Tables I and II and plotted in the diagram of Fig. 2. All ages are based upon the Rb decay constant of $1.42 \times 10^{-11} a^{-1}$ (STEIGER & JÄGER, 1977). The errors in the isochron calculations are at the 95% confidence level.

The biotites reveal two distinctly different Rb-Sr ages. Two, both from the northwestern corner of the island, have an age of about 85 Ma. The other two biotites, from the central part of the batholith, show ages of about 70 Ma. Due to the unfavourable low Rb/Sr ratios, it is impossible, within the limits of error, to distinguish with certainty between the two age groups among the whole-rock data. The four samples from N.W. Aruba do show, however, a tendency towards a steeper alignment than the other samples (Fig. 2). If we connect the four whole-rock data-points from N.W. Aruba with the two biotite data-points from the same area, we obtain an isochron with an age of 85.1 ± 0.5 Ma and initial $^{87}Sr/^{86}Sr$ of 0.7033 ± 0.0002. The two biotites from central Aruba together with the remaining whole-rock data-points also give a good isochron, corresponding to an age of 70.4 ± 2.0 Ma and initial $^{87}Sr/^{86}Sr$

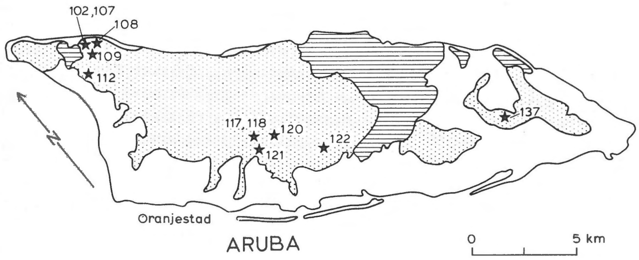

Fig. 1
Geological sketch map of Aruba, simplified after Westermann (1932). Stippled: tonalitic batholith; horizontal shading: sequences of metavolcanics and metasediments; blanc areas: Late Tertiary and Quaternary deposits (mainly coral reefs). The stars and numbers refer to the investigated samples.

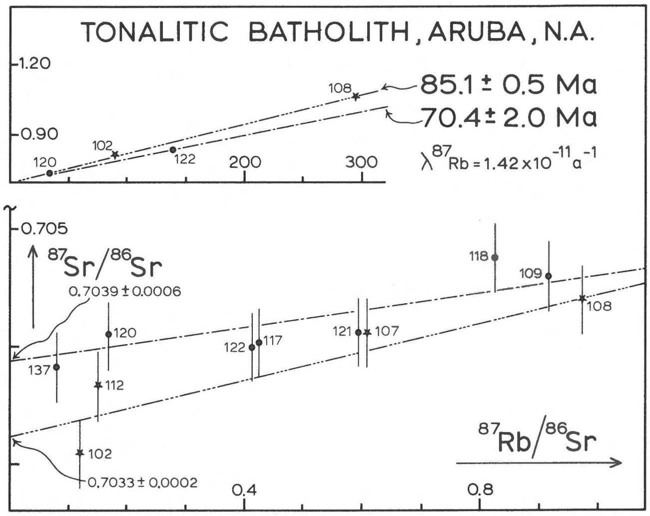

Fig. 2
Plot of Rb-Sr data. Stars: samples from N.W. Aruba; closed circles: samples from other parts of the batholith.

of 0.7039 ± 0.0006. This younger isochron includes one sample from N.W. Aruba (Ant 109), a granodiorite vein cutting the main tonalitic mass in this area.

From the Rb-Sr data we conclude that the tonalitic batholith of Aruba is made up of (at least) two separate intrusions some 15 Ma apart. The older part, preserved in the northwestern corner of the island, was emplaced about 85 Ma ago. The younger intrusion, probably forming the greater part of the batholith, took place about 70 Ma ago, confirming the Rb-Sr and K-Ar dates obtained earlier on a single biotite from central Aruba (PRIEM ET AL., 1966).

DISCUSSION

Two time-scales for the Late Cretaceous have been proposed recently, one by OBRADOVICH & COBBAN (1975) and the other by VAN HINTE (1976). Both papers approximately agree on the time interval assigned to the Maastrichtian, 66/67 Ma (O & C) or 67 Ma (VH) for the Maastrichtian/Tertiary boundary, and 70/71 Ma (O & C) or 72 Ma (VH) for the Campanian/Maastrichtian boundary (all dates converted +2.5%, using the new set of K constants recommended by STEIGER & JÄGER, 1977). The age of 70.4 ± 2.0 Ma places the intrusion of the main part of the batholith thus in the Maastrichtian. Regarding the northwestern part of the batholith the age of 85.1 ± 0.5 Ma falls within the interval Coniacian-Santonian, in view of the dates of 89 Ma (O & C) or 88 Ma (VH) and 84 Ma (O & C) or 80 Ma (VH) assigned to the boundaries Turonian/Coniacian and Santonian/Campanian, respectively. The Coniacian/Santonian boundary is taken at 88 Ma by Obradovich & Cobban and at 84 Ma by Van Hinte, but no reliable isotopic dates are available directly bearing on this boundary. It is thus not well possible to fit the age of 85.1 ± 0.5 Ma accurately in the biostratigraphic time-scale, other than within the interval Coniacian-Santonian.

PLATE TECTONIC INTERPRETATION

Before attempting to interpret the episodic tonalitic magmatism on Aruba in terms of the geologic evolution of the Caribbean region, it is appropriate to summarize briefly the magmatic history of the Leeward islands of the Netherlands Antilles (Aruba, Curaçao and Bonaire) as envisaged by BEETS & MAC GILLAVRY (1977):

(1) An Early Cretaceous (?Aptian) to Coniacian phase with abundant submarine volcanism of the tholeiitic series (SANTAMARÍA & SCHUBERT, 1974; DONNELLY ET AL., 1973; DONNELLY & ROGERS, 1978; BEUNK & KLAVER, 1977) During this phase thick monotonous sequences of basic volcanics with a chemistry similar to that of mid-ocean ridge basalt were formed (Curaçao Lava Formation; diabase-schist-tuff formation of Aruba), or thick sequences ranging in composition from basalt to rhyodacite and belonging to the primitive island arc suite (Washikemba Formation of Bonaire). Terrigenous detritus, if present, is wholly made of volcaniclastic debris.

(2) A late Senonian-Palaeocene phase with less magmatic activity and an increase in clastic sedimentation, as appears from sections on Curaçao and Bonaire. No sediments of this phase have been found on Aruba. The igneous rocks belong to the calc-alkaline series (SANTAMARÍA & SCHUBERT, 1974; BEUNK & KLAVER, 1977). On the basis of earlier data (PRIEM ET AL., 1966) it was thought that intrusion of the entire batholith of Aruba took place in this interval. Influx of sialic detritus on Curaçao shows the proximity of the South American continent during this phase.

Table I
Tonalitic batholith Aruba, whole-rocks

Sample Nr.	Rb[1] (ppm Wt)	Sr[1] (ppm Wt)	Rb/Sr[1] (Wt/Wt)	$^{87}Sr/^{86}Sr$[2]	$^{87}Rb/^{86}Sr$
northwestern part					
Ant 102	18.0	444	0.0405	0.70298 }	0.1171
				0.70321 }	
Ant 107	52.3	250	0.2098	0.70414	0.6074
Ant 108	54.3	162	0.3356	0.70440	0.9716
Ant 112	15.4	299	0.0516	0.70367	0.1494
	15.7⁺				
main batholith					
Ant 109[3]	55.5	176	0.3163	0.70460	0.9158
Ant 117	28.8	196	0.1466	0.70404	0.4244
Ant 118	44.9	158	0.2848	0.70476	0.8246
Ant 120	15.6	271	0.0575	0.70411	0.1663
	15.6⁺				
Ant 121	13.6	66.3	0.2050	0.70413	0.5935
Ant 122	26.5	186	0.1422	0.70400	0.4117
Ant 137	6.06	220	0.0276	0.70383	0.0799
	6.08⁺				

1 X-Ray fluorescence spectrometric data, except for the figures marked ⁺ which were obtained by isotope dilution analysis.
2 Direct measurements on unspiked samples.
3 Vein cutting main mass in northwestern part.

Table II
Tonalitic batholith Aruba, biotites

Sample Nr.	Rb[1] (ppm Wt)	Sr[1] (ppm Wt)	$^{87}Sr/^{86}Sr$[2]	$^{87}Rb/^{86}Sr$	Age[3] (Ma)
Ant 102	214	6.95	0.81157	89.84	
	212	7.02	0.80964	88.18	85 ± 2
	213	7.00	0.81132	89.05	
Ant 108	352	3.62	1.0584	291.7	85 ± 2
	354	3.61	1.0582	294.0	
Ant 120	175	15.4	0.73833	32.84	74 ± 3
	174	14.7	0.74029	34.47	
Ant 122	294	6.19	0.83959	139.3	69 ± 2
	294	6.21	0.83956	138.9	

1 Isotope dilution.
2 Calculated from isotope dilution run.
3 Calculated with respect to the corresponding whole-rock sample. Errors based upon estimated errors of 1% in Rb and Sr, and 0.05% in $^{87}Sr/^{86}Sr$. Decay constant $1.42 \times 10^{-11} a^{-1}$ (STEIGER & JÄGER, 1977).

The two phases are separated by an unconformity, as appears from sections on Curaçao and Bonaire.

The interpretation of the Early Cretaceous to Coniacian magmatic phase has been the subject of considerable debate. On the basis of geologic arguments MARESCH (1974, 1976) and BEETS & MAC GILLAVRY (1977) assume that the volcanics are part of an oceanic island arc which collided with the South American continent in the interval between the Coniacian and the Campanian. On the other hand, DONNELLY ET AL. (1973), DONNELLY (1975) and DONNELLY & ROGERS (1978) assume, on the basis of the main and trace element chemistry, that the basalts of the Curaçao Lava Formation and the Aruban diabase-schist tuff formation have been formed in an extensional environment (ocean floor). In their most recent paper, DONNELLY & ROGERS (1978) suggest that the basalt sequences are allochthonous and obducted on the continental margin. So, despite the controversy about the tectonic environment in which the volcanics have been formed, all authors agree that the rocks have not been formed on the continental margin of northern South America, but have been tectonically transported towards this margin. This in contrast to the younger, Late Senonian-Palaeocene, calc-alkaline phase, which is considered to represent an island arc upon the continental margin of northern South America (SANTAMARÍA & SCHUBERT, 1974; MARESCH, 1974; BEETS & MAC GILLAVRY, 1977). This island arc developed above a southward-dipping Benioff zone in response to continuing plate movement after collision of the island-arc or obduction of the ocean floor.

In order to interpret the 85.1 ± 0.5 Ma age for the northwestern part of the Aruban tonalitic batholith, it is of prime importance to date the actual collision or obduction. The youngest age for the older phase comes from the Washikemba Formation of Bonaire where Early Coniacian inoceramids (det. E. G. Kauffman in BEETS ET AL., 1977) occur in the upper part of the unit. The oldest age of the Late Senonian phase is Campanian, based on rudists in the section of Curaçao (BEETS, 1977). Collision must thus have taken place in the time span between these dates. As is discussed above, the approximately 85 Ma old episode of tonalitic magmatism on Aruba falls in the interval Coniacian-Santonian. In view of the fact that in the Late Senonian the subduction must already have proceeded 80 to 100 km before calc-calkaline magma could have been generated, we think that the tonalite of northwestern Aruba belongs to the older magmatic phase of the islands.

The model of magmatic episodicity for the development of the tonalitic batholith on Aruba will be tested by detailed mapping, chemical investigations and additional isotopic dating.

ACKNOWLEDGEMENTS

The authors thank Prof. Dr. H. J. Mac Gillavry, University of Amsterdam, for helpful discussions. This work forms part of the research programme of the 'Stichting voor Isotopen-Geologisch Onderzoek', supported by the Netherlands Organisation for the Advancement of Pure Research (Z.W.O.).

REFERENCES

Beets, D. J. 1977 Cretaceous and Early Tertiary of Curaçao – 8th Car. Geol. Conf. (Curaçao) Guide to field excursions: 7-18.

Beets, D. J. & H. J. Mac Gillavry 1977 Outline of the Cretaceous and Early Tertiary history of Curaçao, Bonaire and Aruba – 8th Car. Geol. Conf. (Curaçao) Guide to field excursions: 1-7.

Beets, D. J., H. J. Mac Gillavry & G. Klaver 1977 Cretaceous and Early Tertiary of Bonaire – 8th Car. Geol. Conf. (Curaçao) Guide to field excursions: 18-29.

Beunk, F. F. & G. Klaver 1977 Geochemistry of the igneous rocks of Bonaire, Aruba and Curaçao – Abstr. 8th Car. Geol. Conf. (Curaçao): 17-18.

Donnelly, Th. W. 1975 The geological evolution of the Caribbean and Gulf of Mexico. In: A. E. M. Nairn & F. G. Stehli (eds.): The ocean basins and margins (vol. 3): 663-684.

Donnelly, Th. W., W. Melson, R. Kay & J. J. W. Rogers 1973 Basalts and dolerites of Late Cretaceous age from the central Caribbean – Initial Rept. DSDP 15: 989-1011.

Donnelly, Th. W. & J. J. W. Rogers 1978 The distribution of igneous rock suites throughout the Caribbean – Geol. Mijnbouw (this issue).

Helmers H. 1977 The hooibergites of Aruba – a preliminary note – Abstr. 8th Car. Geol. Conf. (Curaçao): 70-71.

Helmers, H. & D. J. Beets 1977 Geology of the Cretaceous of Aruba – 8th Car. Geol. Conf. (Curaçao) Guide to field excursions: 29-35.

Maresch, W. V. 1974 Plate-tectonic origin of the Caribbean Mountain System of northern South America: discussion and proposal – Geol. Soc. Am. Bull. 85: 669-682.

—— 1976 Implications of a Mesozoic to Early Tertiary collision-type plate-tectonic model in northern Venezuela for the southern Caribbean region – Trans. VII Car. Geol. Conf. (Guadeloupe): 485-491.

Obradovich, J. D. & W. A. Cobban 1975 A time-scale for the Late Cretaceous of the Western Interior of North America – Geol. Ass. Canada Spec. Paper 13: 31-54.

Priem, H. N. A., N. A. I. M. Boelrijk, R. H. Verschure, E. H. Hebeda & R. A. Lagaay 1966 Isotopic age of the quartz diorite batholith on the island of Aruba, Netherlands Antilles – Geol. Mijnbouw 45: 188-190.

Santamaría, F. & C. Schubert 1974 Geochemistry and geochronology of the southern Caribbean – northern Venezuela plate boundary – Geol. Soc. Am. Bull. 85: 1085-1098.

Steiger, R. H. & E. Jäger 1977 Subcommission on Geochronology: convention on the use of decay constants in geo- and cosmochronology – Earth Planet. Sci. L. 36: 359-362.

Van Hinte, J. E. 1976 A Cretaceous time scale – Amer. Ass. Petr. Geol. Bull. 60: 498-516.

Westermann, J. H. 1932 The geology of Aruba – Ph. D. thesis Utrecht Univ.: 129 pp.

NOTE ADDED IN PROOF

After the completion of the manuscript, an additional Rb-Sr whole-rock analysis was obtained from a pegmatitic differentiate in the batholith, 1 km E of the village Noord (N of Oranjestad). The analytical data are: Rb, 143 ppm; Sr, 46.3 ppm; Rb/Sr, 3.0860; $^{87}Sr/^{86}Sr$, 0.71426; $^{87}Rb/^{86}Sr$, 8.934. This sample also fits to the isochron of the younger part of the batholith. Inclusion of the pegmatite into the isochron calculation virtually does not affect the result: 70.5 ± 2.2 Ma and initial $^{87}Sr/^{86}Sr = 0.7040 \pm 0.0006$.