THE STRATIGRAPHY AND AGE OF THE WHITE WALL-SUGAR LOAF SEQUENCE, ST.EUSTATIUS

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ABSTRACT

The composition and form of active volcanic islands and their surrounding submarine platform is the result of a complex interplay among subduction rates, magmatic evolution, eruptive styles, local tectonics and sea level changes. Stratigraphic sections containing intercalated proximal volcanic products and calcareous layers are ideally suited to study these relationships. In addition, corals, within the calcareous layers, can be dated, thus setting variations in volcanic activity and sea level changes in a time frame for comparison with global sea level fluctuations. The uplifted White Wall-Sugar Loaf sequence on the southwestern flank of the Quill volcano, St. Eustatius provides an excellent example of the above relationship. This sequence is composed of shallow water platform limestones, often with corals in their position of growth, interbedded with andesitic to rhyolitic pumice horizons. Previous dating of this sequence by Westermann and Keil (1961) using ^{14}C suggested that the limestones were deposited between 40,000 and 20,000 years ago. More recent analyses, using U-Th series dating, have shown that the upper part of the section, the Sugar Loaf, ranges in age from 300,000 to 68,000 years B.P., thus making the sequence much older than previously thought. The implications of these ages in terms of global sea level changes will be discussed, and a model will be developed to explain the initial emergence of the Quill volcano. This paper is a contribution to IGCP project 364.

INTRODUCTION

The island of St. Eustatius at the northern end of the Active Arc of the Lesser Antilles (Roobol and Smith, 1989; Smith and Roobol, 1991) can be divided into three geological units (Fig. 1). The first unit is the Northern Centers which is composed of a number of highly eroded volcanic centers composed of a combination of volcanic domes, thick lava flows and volcaniclastic deposits (both pyroclastic and reworked). K/Ar dating of lava flows from this unit produced ages of less than 1Ma (Roobol et al., 1996). The second unit is the potentially active Quill volcano located in the southern part of the island. This volcano is composed entirely of pyroclastic deposits with little reworked material and its flank deposits on the north extend up tp and have on occassions overtopped the older Northern Centers (Roobol et al., 1996). The exposed subaerial deposits of the Quill appear to have formed between 28,000 and 1,500 years B.P. (Roobol and Smith, 1989; Roobol et al., 1996), and include the products of Plinian-, Pelean-, and St. Vincent-style eruptions (rrobol and Smith, 1989). The third unit is an uplifted series of limestones and interbedded volcaniclastic deposits on the southwestern flank of the Quill known as the White Wall-Sugar Loaf sequence.

PREVIOUS WORK

The depositsof the White Wall-Sugar Loaf were initially studied by Molengraaff (1931) and later by Westermann and Keil (1961). A sketch of the Sugar Loaf by Molengraaf (1931) showing his different lithologic units is given in Figure 2, and a comparison of the stratigraphies of both Molengraaff (1931) and Westermann and Keil (1961) are given in Table 1.

^{14}C age dating of corals by Westermann and Keil (1961) from three limestone beds, two from the Sugar Loaf and one from the top of the White Wall are given in Table 2. These dates suggest that the deposition of the Sugar Loaf sequence occurred between 40,000 and 20,000 years B.P., and thus partially overlapped in age the eruptions that generated the older subaerial pyroclastic deposits of the Quill.

STRATIGRAPHY OF THE SUGAR LOAF SEQUENCE

A new stratigraphic section through the Sugar Loaf sequence is presented in Figure 3. At the base of the section immediately on top of the limestones of the White Wall is a thin bed of fine white ash containing pumice clasts and coral fragments. This is overlain by 6m of fine grained pumice breccia, which is in turn overlain by a succession of volcaniclastic beds ranging from fine-grained white laminated ash to cross-bedded sandstones and conglomerates. This succession terminates in a conglomerate bed containing rounded lava fragments. On top of the conglomerate is a 3 to 4m thick limestone bed containing tabular corals in their position of growth. An angular unconformity separates the limestone from a clast-supported pumice breccia. The latter contains pumice blocks up to 70cm in size. This passes up into a matrix-rich breccia containing well rounded blocks of pumice as well as coral fragments. The matrix of this bed is composed of fine-white ash often showing slump structures. Following

these volcanic deposits are a yellow limestone with dense andesite clasts, a limestone breccia and a fine grained limestone again with corals in their position of growth. The uppermost beds in the stratigraphy are a series of dark, fine-grained ashes contained quenched bombs, and ballistic fragments of dense lava and coral.

AGE OF THE SUGAR LOAF

Corals from four beds from the Sugar Loaf sequence were collected and dated. The sampled corals were first inspected for secondary calcite growth and then analysed by X-ray diffraction spectrometry to ascertain that the original aragonite had not changed to calcite. On the basis of these inspections seven samples were considered to be unaltered and were thus submitted for U/Th series age dating. The ages obtained are presented in Table 3 and plotted in Figure 4. The oldest dates were obtained from coral clasts contained in the volcaniclastic bed immediately overlying the limestones of the White Wall. These dates range from >320,000 to 250,000 years B.P. Corals from the lowest limestone bed yielded ages of 218,000 and 234,000 years B.P. which are very similar to the U/Th ages of 236,000 $\pm$ 7,458 and 218,500 $\pm$ 7,866 years B.P. originally obtained from this deposit (Smith, unpub. data). Corals from the limestone breccia near the top of the section gave an age of 130,000 years B.P., whereas those in the overlying limestone yielded a considerably younger age of 68,000 years B.P.

DISCUSSION

The fauna (corals, molluscs and gastropods) obtained from the limestone beds of the White Wall-Sugar Loaf all indicate a shallow (<10m) back reef platform environment which must have existed for over 250,000 years (Table 3). Based on these data it is suggested that between 400,000 and 300,000 years ago St. Eustatius was composed of a island formed by the volcanoes of the Northern Centers flanked to .the south by a shallow marine platform on which patch reefs were growing (Fig. 4). Erosion of the deposits of the Northern Centers occassionally brought significant influxes of clastic sediment on to the plaform as evidenced by the beds of sandstone and conglomerate. Also at times the platform must have been almost emergent as the White Wall contains sedimentary gypsum deposits (Smith unpub. data) presumably formed by evaporation of sea water (Fig. 4).

As very little evidence can be seen in the deposits of the White Wall-Sugar Loaf for subaerial volcanism it has been assumed that the Nothern Centers were extinct or almost extinct by this time. In contrast there is considerable evidence for subaqueous volcanism suggesting that it was during this time period that the Quill began to form. The first eruptive unit for which we have age control is found at the base of the Sugar Loaf succession and must have been produced between 250,000 and 230,000 years ago. This eruption is now represented by a fine-grained andesitic pumice breccia and fine grained laminated white ashes. The former probably represents a pumice raft or the remains of a tuff ring, whereas the latter are the products of phreato-magmatic explosions produced when sea water came in contact with the hot andesitic magma (Fig. 4). This eruptive activity was followed by a quiescent

period when coral reefs re-established themselves on the platform.

Renewed explosive activity (<218,000 years B.P.), this time of rhyolitic composition, produced the upper pumice and ash deposits of the Sugar Loaf. The matrix-supported pumice beds ontop of the pumice breccia has been interpreted to represent a succession of debris flows that probably moved from the tuff ring into deeper water. After this volcanic activity ceased carbonate sedimentation again dominated the platform for about 130,000 years. This quiescent period was terminated some time after 68,000 years B.P. by the eruption of basaltic magma, now represented by the dark phreatomagmatic ashes at the top of the Sugar Loaf succession (Fig. 4). It is possible that these eruptions marked the beginning of the main cone building phase of the Quill as carbonate deposition was no longer able to re-establish itself and by at least 28,000 years B.P. the platform had been built above sea level The present-day configuration of uplifted and tilted limestones and interbedded volcaniclastic deposits that now make up the White Wall-Sugar Loaf was probably caused by the intrusion of a cryptodome into the volcanic edifice of the Quill.

ACKNOWLEDGEMENTS

Research was supported by grants from the National Science Foundation (EAR 77-17064, RII 88-02961 and HRD 93-53549), and the University of Puerto Rico. Thanks are extended to B. Gunn for cooperation with some of the field work, and to B. Taggart for X-ray diffraction analyses and U/Th age dating which was underetaken at the laboratory of Dr. W.S Moore of the University of South Carolina; U/Th series dating was conducted by Dr. W. Burnett of the Department of Oceanography at Florida State University at Tallahassee, Florida.

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TABLE 1 STRATIGRAPHY OF SUGAR LOAF AND WHITE WALL, ST. EUSTATIUS (after Westermann and Keil, 1961)

		Molengraaff	Westermann & Keil	Approximate position: stratigraphic thickness (3) or distance (-3) in meters	Lithology
				foot of outer slope	tuff, fossiliferous
			31a	3	coquina
			b	6	coral limestone
	Western foot	1	c	1	coquina and other limestone
SUGAR			d	4	coral limestone
			e	5	coral limestone
		2	55d	1.5	conglomerate of volcanic material and fossil fragments
		3	c	3	very fine-grained limestone
LOAF		4	b	4	pumice
		5	-	2	coral limestone
	crest	6	a	5	limestone
		7	31f	2	conglomeratic tuff, fossiliferous
		8	g	7	tuff with pumice fragments, without fossils
		9	h	7	calcareous and brecciated tuff, without fossils
		below 9		-	tuff?
	on top of	saddle with	32	upper stratum	coral limestone
	below	Sugar Loaf	56	upper stratum	coral limestone
			54a	-3	lithothamnium limestone
			b	-10	"
			c	-13	"
WHITE			d	-13	"
	Big Gut		e	-9	"
WALL			f	-1	"
			g	-7	"
			h	-7	"
			i	-18	"
			j	-3	"
			k	-18	coquina
			l	-18	lithothamnium limestone
			m	-30	tuff, without fossils

TABLE 2 **^{14}C AGES FROM CORAL SPECIMENS FROM THE WHITE WALL-SUGAR LOAF, ST. EUSTATIUS (after Westermann and Keil, 1961)**

Location	Stratigraphic bed after Westermann & Keil	Age (Years B.P.)
Sugar Loaf	31b	21,850 ± 100
Sugar Loaf	55a	>49,000
White Wall	32	32,640 ± 300

TABLE 3 **U/TH SERIES AGES OF CORALS FROM ST. EUSTATIUS**

Sample	U ppm	Th ppm	U^{234}/U^{238}	Th^{230}/U^{234}	Th^{230} Age (1000yrs)
SE-26	2.70 ± 0.06	0.010 ± 0.03	1.06 ± 0.01	0.97 ± 0.04	>320
SE -28	2.86 ± 0.08	<0.005	1.04 ± 0.02	0.95 ± 0.04	300 ± 103
SE -27	2.91 ± 0.08	<0.005	1.07 ± 0.01	0.92 ± 0.04	251 ± 49
SE -30	2.26 ± 0.06	<0.005	1.09 ± 0.01	0.90 ± 0.03	234 ± 35
SE -29	2.86 ± 0.08	<0.005	1.09 ± 0.01	0.88 ± 0.03	218 ± 29
SE - 24	2.68 ± 0.06	<0.005	1.12 ± 0.01	0.71 ± 0.03	130 ± 9
SE - 33	2.85 ± 0.07	<0.005	1.11 ± 0.01	0.47 ± 0.02	68 ± 3.4

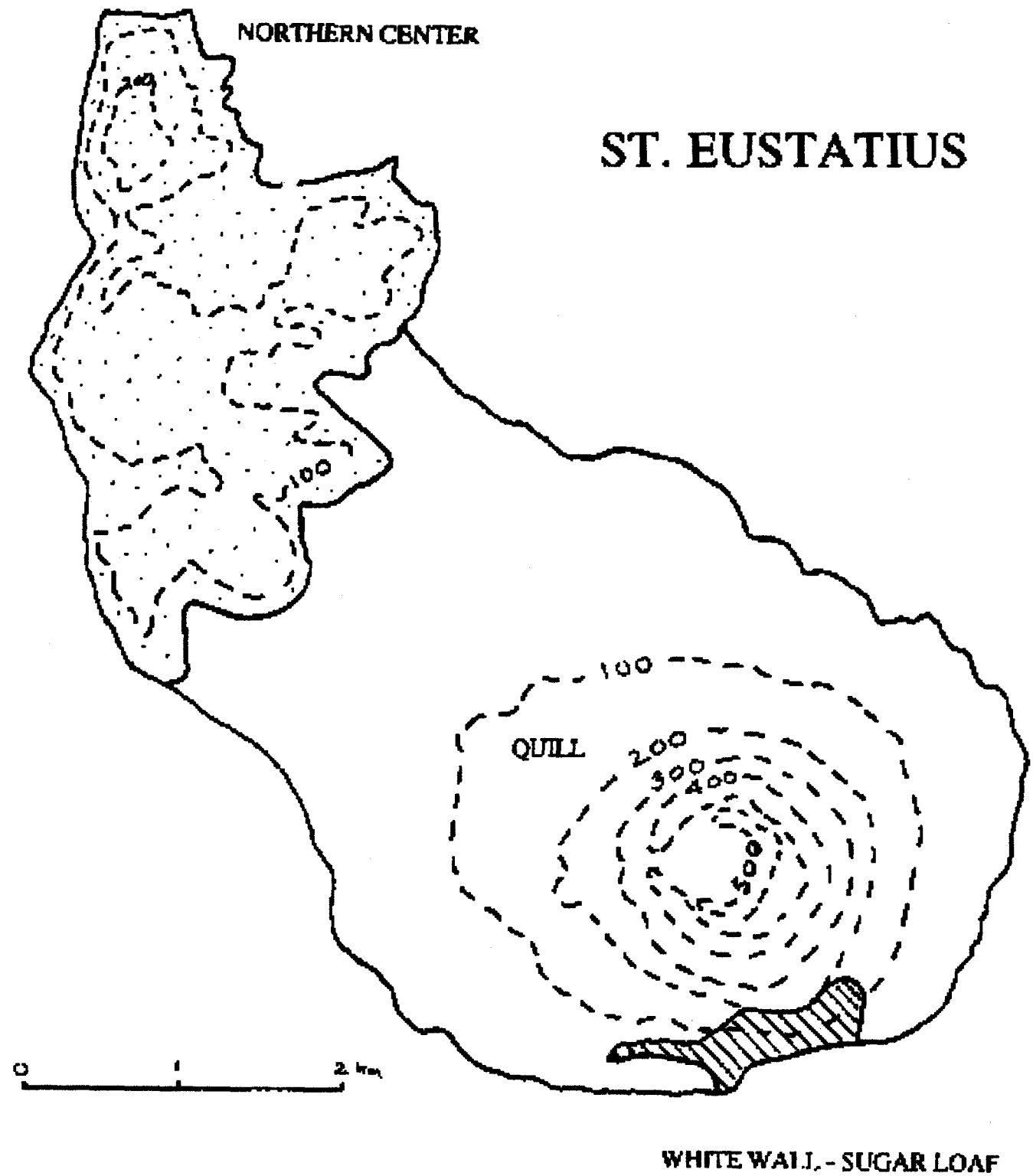

Fig.1 **Sketch map of St. Eustatius showing the locations of three geological units referred to in the text: the Northern Centers; the Quill volcano; and the White Wall - Sugar Loaf.**

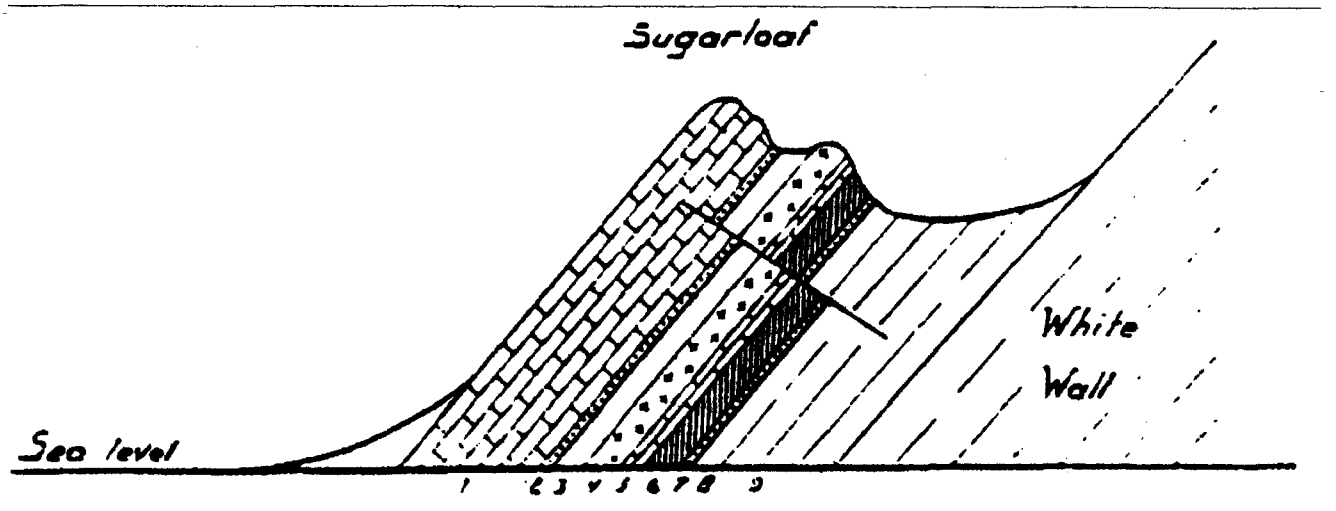

Fig. 2 **Sketch of the strata visible in the eastern slope of Sugar Loaf 1885: 1. Coral rock 2. Conglomerate with corals and shells 3. Pumice-tuff 4. Dacite-pumice 5. Coral rock 6. Soft limestone with corals and shells 7. Conglomerate with some shells and corals 8. Yellowish tuff 9. Whitish tuff (after Molengraaff, 1931).**

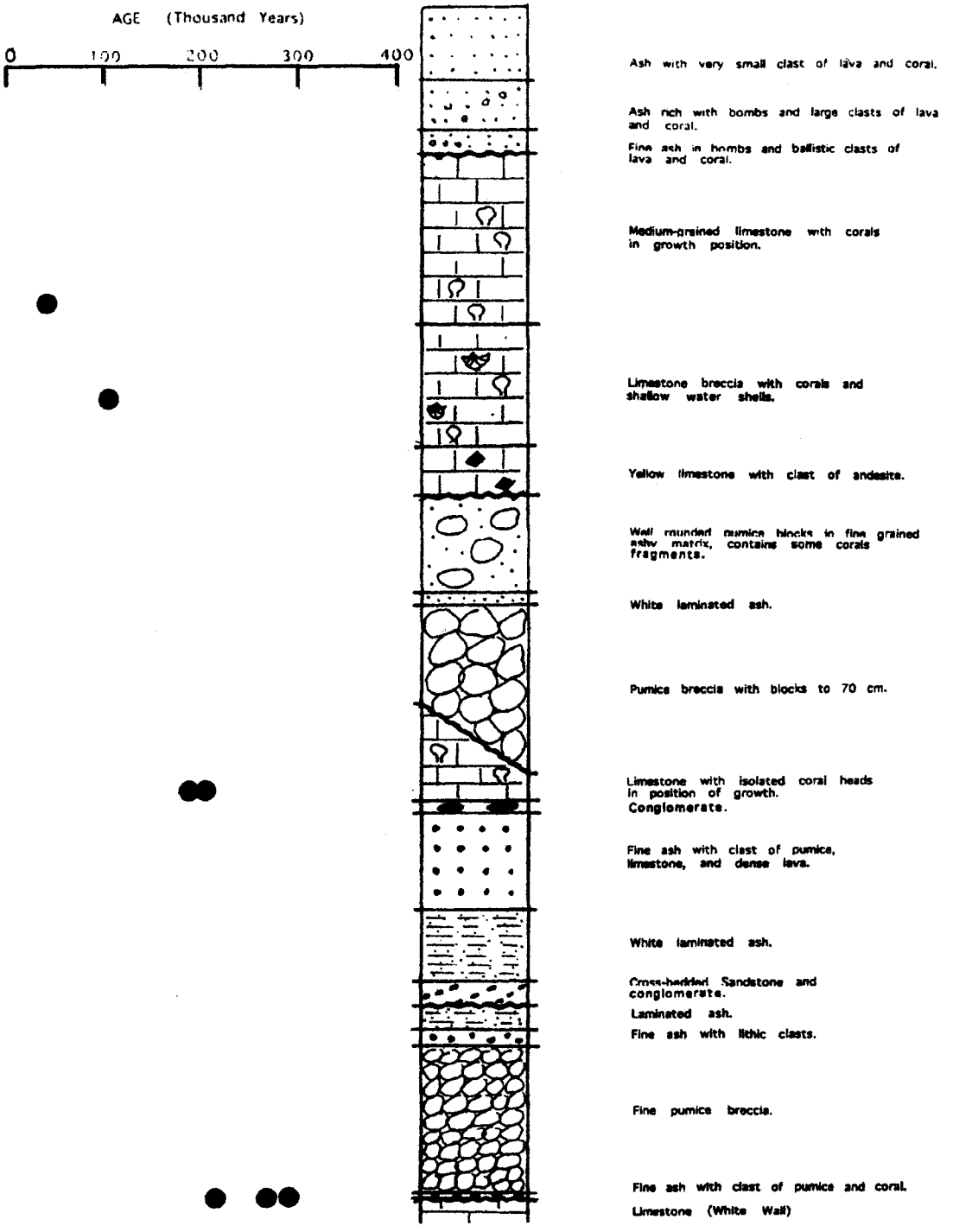

Fig. 3. Stratigraphic column through the sugarloaf. Dates are U/Th series ages from included cxorals given in Table 3.

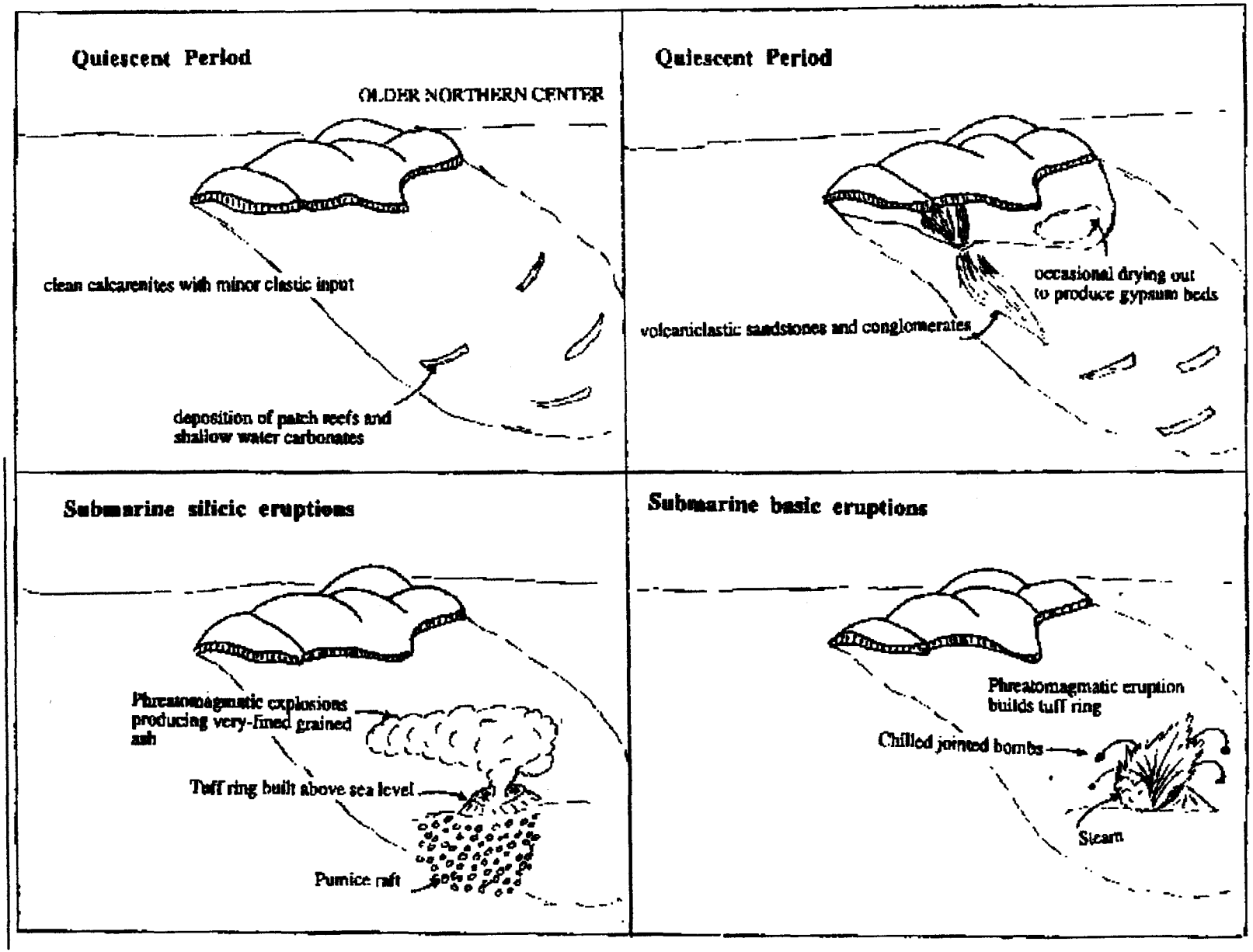

Fig. 4 Diagrammatic sketches of possible scenarios in the evolution of the marine carbonate platform, Southern St. Eustatius between 400,000 and 50,000 years B.P.