St. Croix Geology since Whetten: An Introduction

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Ancient Environments of St. Croix

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INTRODUCTION

Almost thirty years ago, John T. Whetten completed the field work for the most comprehensive geological investigation of the island of St. Croix ever done before or since. This study, done as part of his PhD work at Princeton University under H.H. Hess, established a stratigraphic column, added petrological, paleontological, structural, and tectonic information and produced what is still the most detailed map of the older sedimentary and igneous rocks of the entire island. The map and an edited version of his thesis text were, later published by the Geological Society of America (Whetten, 1966) and as a contribution to the "Geology and Ecology" volume published by West Indies Laboratory in 1974 (a simplified map is included as Figure 1). Whetten's study focused primarily on the Upper Cretaceous rocks of the island and did not deal with the Tertiary rocks or the modern carbonates in any detail .

Since the publication of this pioneering work, numerous investigators have continued to work on the Cretaceous rocks of St. Croix. In addition, interest has expanded to the Tertiary and Quaternary sedimentary facies. The purpose of this brief prefatory article is to first summarize the thinking at the time of Whetten and, later, the publication of "Geology and Ecology of St. Croix". In addition, some very general information on geological studies that have been completed since then is provided. It is hoped that the following pages will in part bridge the gap between this guidebook and the last one published over a decade ago, and thus set the stage for the articles that follow.

WHETTEN'S EARLY WORK

Within the Cretaceous rocks, Whetten described a basal sedimentary unit composed of several rock types; mudstones being most abundant, and in order of decreasing importance: sandstones, limestones, cherts and conglomerates. This unit, termed the Caledonia Formation for the well exposed section exposed in the Caledonia Valley in northwestern St. Croix, is present on both the western and eastern ends of the island. These exposures are separated by outcrops of Tertiary rocks located in what Whetten pictured as graben in central St. Croix. Many of the sandstone units of the Caledonia contain keratophyre and spilite fragments. The observation that the keratophyre/spilite ratio of the Caledonia clasts is about the same as that of the volcanic rocks of the Water Island Formation, the basal formation in the northern Virgin Islands (Donnelley, 1966; Helsey, 1960), and very preliminary directional data, prompted Whetten to look toward the north for a source area for the "epiclastic" (derived from older volcanic rocks by sedimentary processes) portions of the Caledonia Formation. More recent detailed examination of the directional features in these sediments by Dan Stanley (1987a, 1987b, 1988) has not ruled out a northward source but has introduced the complication of reworking of the Caledonia turbidites by strong bottom currents flowing to the west.

The Caledonia Formation is overlain by the Judith Fancy Formation in both western and central-eastern St. Croix. Whetten describes this formation as a thick sequence of "tuffaceous" rocks having a major component of primary pyroclastic materials. The assumption of pyroclastic origin for tuffaceous constituents in this and other tuffaceous units was based upon "the angularity of the grains, the large amount of devitrified glassy fragments, and the fine grained slightly birefringent matrix which suggests devitrified glass shards" (page 202, Whetten, 1966). Volcanic breccias in this unit are described as having boulders 3 feet and over in diameter and averaging 2-6 inches. The most common are andesite and dacite flow fragments; keratophyre and spilite constituents are rare.

Other units having a major tuffaceous component, interpreted by Whetten as interfingering (i.e. facies changes) within the Caledonia Formation, are present on both the eastern and western ends of St. Croix. Whetten's interpretation of the slump structures in these rocks and of the coarsening direction of the pyroclastic material led him

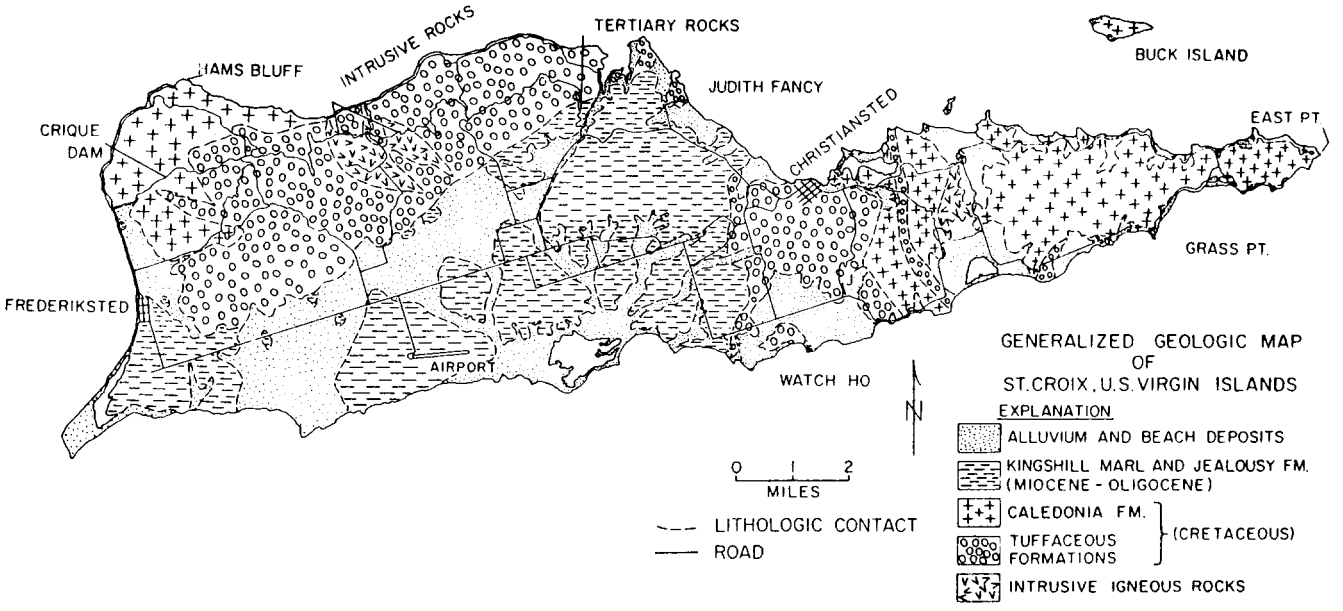

Figure 1. Generalized geologic map of St. Croix. After Whetten (1974).

to postulate an eruptive volcanic source to the southeast of St. Croix between St. Croix and Saba. In this regard, it is interesting to note that amphiboles from andesitic rocks recovered in dredge hauls from the northernmost extension of Saba Bank (Bouysse *et al*, 1985) have yielded Late Cretaceous ages.

Whetten noted that the Cretaceous rocks of St. Croix, and in particular the tuffaceous rocks, have undergone low-grade regional metamorphism probably due to a higher than normal geothermal gradient. He also described several areas of contact metamorphism.

Fossils were collected by Whetten from the Judith Fancy and Caledonia Formations. The ages of those identified (foraminifera, rudists and corals) were all Campanian (possibly Maastrictian from the youngest Cretaceous beds of the Judith Fancy at Vagthus Point).

Whetten's study drew attention to the fact that, unlike most Caribbean islands, the oldest rocks on St. Croix were not predominantly igneous or metamorphosed flow rocks but were sedimentary and that St. Croix and the platform on which it sits must be a remnant of a former Late Cretaceous sedimentary basin. The question as to the location of the rest of the basin has never been answered.

There are, however, some igneous rocks on St. Croix. Whetten describes two stocks (a gabbro and a diorite) and noted that there are a great many small dikes of a wide variety in composition (lamprophyres, basaltic-andesite, rhyolite). Whetten also describes two flows in the Judith Fancy Formation; one from Windsor in the Northside Range, basaltic in compositon, the other from Recovery Hill, East End Range, andesitic in composition. Ratte (1974) describes hornblendites and acid dikes intruding Caledonia Formation on Green Cay. He suggests that these rocks represent a roof or border facies of the Southgate diorite.

Whetten (1966) clearly recognized the difference in major structural trends in the Cretaceous rocks between the eastern and western ends of St. Croix which are separated by a younger graben structure (e.g. Figure 12, page 223 of Whetten, and the simplified structural map from "Geology and Ecology" reproduced as Figure 2 of this paper). This has led to a great deal of informal speculation about the possibility of two different tectonic histories for the two major areas of Cretaceous rocks on either end of the island.

As a result of his analysis of structural data, Whetten called for two generations of folds either in one inhomogeneous deformation or in two separate deformations with maximum compressive stress oriented in a plane first N--NE then later E-SE. As a result of his structural work on the east end of St. Croix, Speed (1979) recognized three episodes of folding. Based on new sea beam and siesmic data north and east of St. Croix, Bouysse *et al.* (1987) proposed a rotation of the compressive stress in the region during Pliocene time from NE-SW to WNW-ESE.

Whetten recognized several faults, most of them normal, but proposed one thrust fault dipping to the east in the Northside Range in western St. Croix. He concluded that a major graben contains the carbonates in central St. Croix, separating the Cretaceous rocks of the eastern and western ends. Except for occurrences of Caledonia and Judith Fancy Formations recognized in both Cretaceous sequences, correlation of units across the graben is impossible.

MORE-RECENT INVESTIGATIONS

Cretaceous Rocks

Interest in the Cretaceous strata of St. Croix has not waned since Whetten's early studies. St. Croix's critical

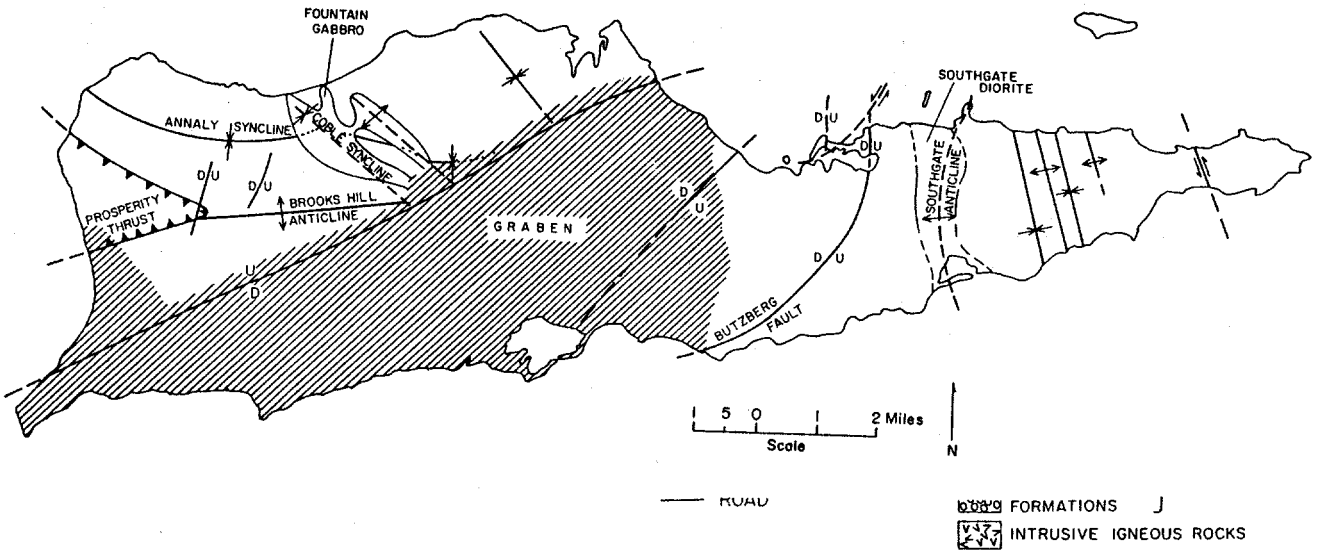

Figure 2*. Generalized structure map of St. Croix. After Whetten (1974).*

position in the Caribbean tectonic province and the anomalous composition of its Cretaceous rocks have made it a focal point for "lively" discussions that continue today. Figure 3 is a simplified geologic column derived primarily from Whetten's work. Some general information on the timing of local and regional tectonic events is also included, based on data collected since Whetten's study. This is far from an exhaustive treatment of the subject, but should provide some useful background information for those not intimately familiar with Caribbean tectonics.

Tectonics - Much of the recent work has been conducted by Bob Speed and Jim Joyce, who author two of the following articles. Important contributions to the tectonic story have also been made by French researchers working in the region.

Speed *et al.* (1979) have published five K-Ar radiometric ages from hornblende separates of igneous rocks, all from the East End (one of which is a clast from the East End Member of the Caledonia Formation). These ages range from 66 ± 3.2 my to 75.2 ± 4.3 my and are the only published radiometric dates from the island. Also in that paper the authors note the discovery of an ammonite (as float) of possible Cenomanian age. It is unclear as to whether it represents primary or reworked material. If it is primary, the Caledonia sediments would be at least 90-100 my old.

In a rather surprising development, a recent USGS geochemical study of the island (Alminas 1986; Alminas *et al.* 1987) identified trace-element tin anomalies on St. Croix. The authors suggest the presence of unmapped acid intrusions. Nagle is currently investigating the occurrence of sulfides in the igneous rocks of the island and disseminated within the Caledonia Formation, and the relation of these sulfides to igneous intrusions.

It is now recognized that St. Croix is segmented into different tectonic fragments. This is now known to be true in Puerto Rico, Cuba, and Hispaniola where correlation of units across major fault zones segmenting those islands is difficult to impossible. By the 1980's it was realized that all of these islands, including St. Croix, were part of a deformed collisional plate boundary which had undergone initial compression followed by transcurrent tectonics and extension. Most agreed that large parcels of terrane were formed in different areas, were then moved long distances, and finally mechanically juxtaposed along fault zones. Often these juxtaposed rocks had little relation to one another as far as their origins were concerned. By the mid-1980's some of the terms and concepts first used in the western U.S. and Alaska such as "tectonostratigraphic" or "suspect terrains" were being applied to the Caribbean. In a comprehensive application to the geologic provinces of the Caribbean, Case *et al.* (1984) grouped St. Croix, its platform, and surrounding sea floor into the "Anegada Province," one of a number of moderately to strongly deformed Tertiary basins in the region.

In this volume, two papers (Speed; Speed and Joyce) interpret the geology of St Croix in a novel and interesting way, quite different from the approach of Whetten (1966) or even the earlier works of Speed (1974, 1979). Partly as an outgrowth of the new modeling of plate-boundary complications and processes, as well as from the realization of the variations in stratigraphy and structural styles on St. Croix noted first by Whetten and later by their own field work, Speed and Joyce suggest that the Cretaceous rocks of St. Croix are a tectonic complex of six fault-bounded, stacked, nappes. They propose that the stratigraphy established by Whetten, based on his perceived facies changes, be abandoned except for use in discussing the rocks as stratal types. On the

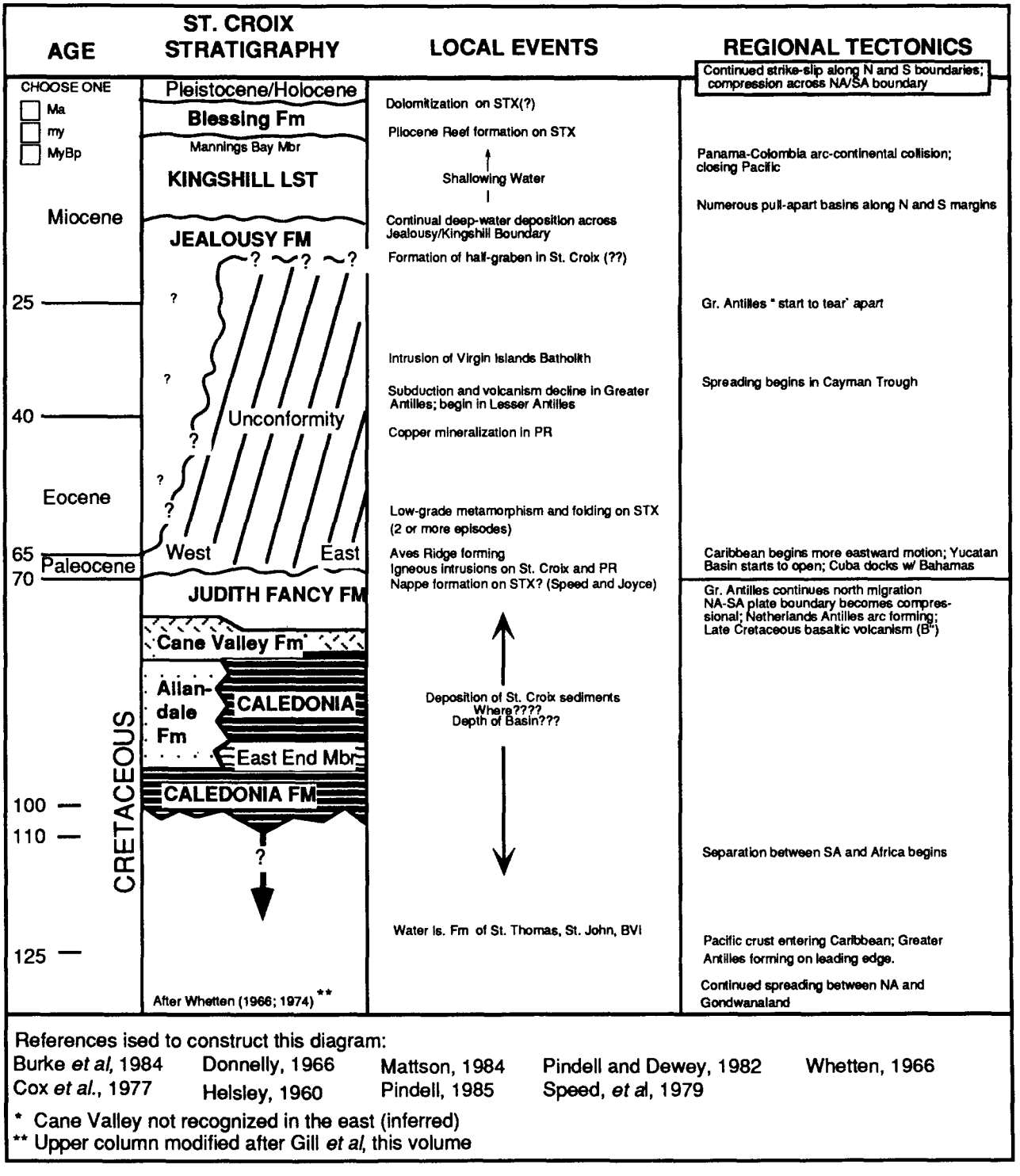

Figure 3. *Generalized geologic column for St. Croix and the NE Caribbean*

basis of their work [which is structurally oriented, not petrologically oriented as is Whetten's] they suggest that the nappes were formed in a forearc of a Late Cretaceous island-arc system facing S to SW. In the first paper Speed proposes that this north-dipping subduction zone expired at the end of the Cretaceous and flipped to southward subduction in the Paleogene, switching St. Croix from a forearc position to a backarc one in the Paleogene.

The discussion caused by these papers is sure to be long-lasting and provide a focal point on our field trips! The uninitiated are going to have to decide whether or not the faults bounding the nappes, which are mostly covered by vegetation and Recent cover, are configured as proposed in the Speed-Joyce model, or on the other hand be convinced by petrographic evidence of Whetten that stratigraphically distinct units can be identified on St.

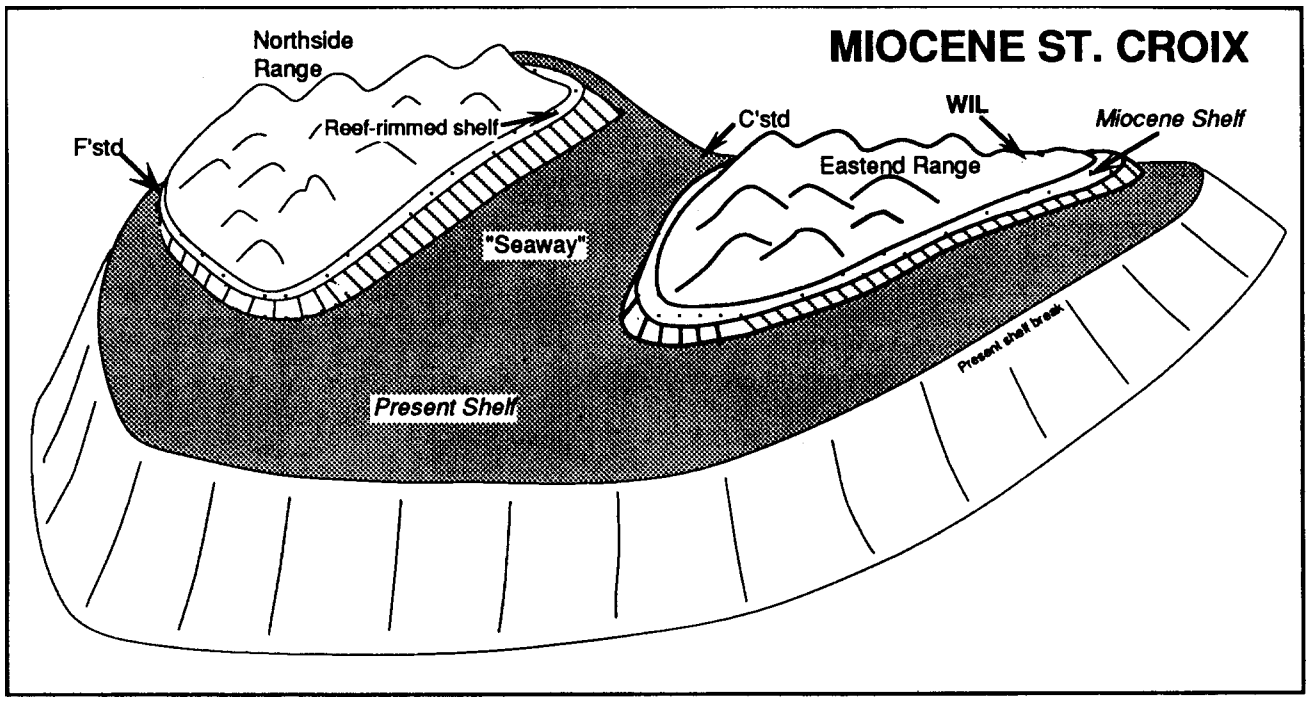

Figure 4. *Schematic diagram of earlier conception of St. Croix in the Miocene.*

Croix, and represent mappable pyroclastic and epiclastic rocks that came simultaneously from different sources and interfingered with one another in a single sedimentary basin.

Sedimentology - Since the earlier descriptions of Whetten, our understanding of depositional processes in the deep sea have greatly broadened. Speed (1974) expanded on Whetten's descriptions and proposed turbidites as the primary mechanism for the emplacement of Caledonia sediments. This position is discussed briefly in his paper in this volume. The most extensive and recent sedimentological studies of the Caledonia Formation have been conducted by Dan Stanley of the Smithsonian Institution. In a paper that follows, he proposes a more complex depositional regime in which oceanographic currents also play an important role in the shaping of Cretaceous basinal sediments exposed on St. Croix. Through the careful examination of large-scale thin sections, he has documented sedimentary structures that are difficult or impossible to see in outcrop. This work, which is described in a following paper (along with several others, e.g. Stanley, 1987a and b; 1988), has made an important contribution to our understanding of Cretaceous St. Croix.

Younger carbonates

Whetten's early remarks about the Tertiary carbonates on St. Croix were generally confined to a structural treatment of the graben that confines them. The bulk of the carbonate sequence is comprised of deep-water planktonic and hemipelagic sediments separated by sediment-gravity flows derived from shallow water. These have been termed the Kingshill Marl by Cederstrom (1941) and later the Kingshill Formation and Kingshill Limestone. In the 1970's a series of papers proposed the existence of a Miocene "seaway" in Whetten's graben (Fig. 4). The East End and Northside Ranges on either end of St. Croix were emergent highlands, supporting shallow-water environments that provided bioclastic debris found in allochthonous deposits of the seaway (Multer *et al.*, 1977; Gerhard *et al.*, 1978). These conclusions were based largely on detailed outcrop investigations. A series of papers by Van den Bold (1970) and Lidz (e.g. 1984, 1988) refined the biostratigraphy of the mid-island region, based primarily on Tertiary ostracods and planktonic foraminifera, respectively.

Until recently, our interpretations were limited by a lack of subsurface data, save cuttings from three deep wells and a preliminary gravity survey. The most recent investigations by Ivan Gill from Louisiana State University have filled that gap, and have dramatically changed our thinking about Tertiary deposition on St. Croix. Detailed analyses have modified our earlier ideas on biostratigraphy and placed deposition in much deeper water than envisioned by earlier workers. This, combined with the physical size of the Kingshill basin on St. Croix all but precludes an intrabasinal source for the shallow-water debris found throughout the exposed section. The results of these studies are summarized in a recently defended PhD dissertation. The paper that follows by Gill

et al. summarizes the findings of these investigations and discusses them within the context of St. Croix geologic history and local tectonics.

Along the northwestern corner of St. Croix, an elevated terrace of likely Pleistocene age rims the island. A paper by Hubbard *et al.* that follows describes this feature, based on outcrop and core data, and proposes a depositional and diagenetic history for these interesting rocks.

The geologic environments exposed on St. Croix are varied, and it is impossible to adequately describe all of them in the confines of a volume such as this. Nevertheless, the following papers represent a broad overview and should provide an interesting introduction for the casual student of natural history or seasoned geologist. Hopefully, the usefulness of these articles will extend beyond that and provoke further investigations into the origin of St. Croix and the Caribbean region.

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