Stone artefact production and exchange among the Northern lesser Antilles
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2 Raw material sources and rock characterisation

2.1 Introduction

This chapter discusses the occurrence and characterisation of specific rock sources within the northern Lesser Antilles and Puerto Rico to identify Amerindian exploited localities and rock distribution patterns throughout the region. Three distinct rock types will be studied, as they commonly occur within the archaeological record of the region. They all can be classified as sedimentary rocks and include different varieties of chert, a grey-green mudstone and a multi-coloured conglomerate. The most significant part of this chapter is dedicated to the study of cherts.[1] The indigenous peoples of the Lesser Antilles used multiple varieties of chert, that are often difficult to distinguish, but which originate from different areas. Therefore, I paid special attention to the mapping of the different sources and the characterisation of the material with the aim of identifying distinguishable features.

This contrasts to the other two materials commonly encountered within the archaeological record, the conglomerate and the mudstone. Both possess very striking characteristics making them easily distinguishable from other rock varieties used for the same purposes. Therefore, these latter characterisation studies only include the microscopic and macroscopic description of both materials and a discussion of their provenances.

2.2 Chert and flint study

2.2.1 Introduction

Chert has been one of the most widely used rock materials for making stone tools during world prehistory and history. Its usage has been identified from Early Paleolithic times, up to today. It functioned as an important raw material, in particular for making flake and blade tools. Earliest evidence of chert usage in the Caribbean corresponds with the first colonization of the islands by Preceramic foragers. These so called Casimiroid people occupied the Greater Antilles and are well known for their blade industries (Keegan 1994; Kozlowski 1974; Rouse 1992). This study will show that chert remained a commonly employed rock type until the end of the indigenous occupation of the islands.

Despite the general utilization of this material, chert was not commonly available to all the region's inhabitants. Its restricted occurrence can to a large degree be explained by the diverse geological build-up of the different islands, in which the Greater Antilles, including the Virgin Islands, experienced a longer, more complex and varied geological formation history than the younger predominantly volcanic Lesser Antilles. As a result, chert is more commonly available in the Greater Antilles than in the Lesser Antilles.

The study of chert distribution provides an excellent case for the identification of inter-island rock material transport and exchange relationships, considering the relatively rare, and more importantly, its very restricted natural occurrences on the Lesser Antilles and its common usage by the indigenous inhabitants. Before chert artefacts excavated at archaeological sites can be assigned to a specific source and before the distribution of a chert material can be mapped, it is first necessary to distinguish a particular chert material from other cherts. Therefore, this chapter will pay particular attention to the sourcing of chert in the northern Lesser Antilles (figure 2.1). To accomplish this, a number of goals have been formulated prior to this research. These include:

a) The mapping of available chert sources and the context(s) in which the chert is found. The islands under consideration included Antigua, St. Kitts and Puerto Rico.

b) The morphological and geo-chemical characterisation of source material to identify criteria by which sources can be discriminated.

c) In addition to the characterisation study, which focuses on the geochemistry of the chert, I also attempted to find explanation(s) for why sources differ chemically. This provides a stronger empirical basis for source discrimination, and may yield guidelines for future research. I attempted to formulate hypotheses about the origin of most of the important trace elements, that are of importance to this study. In addition, special attention was given to the change in composition affected by weathering of the chert because it is believed that weathering played a significant role in this particular region given, the

[1] See the next paragraph for a definition of cherts, followed by a discussion of varieties, which are included within this study.

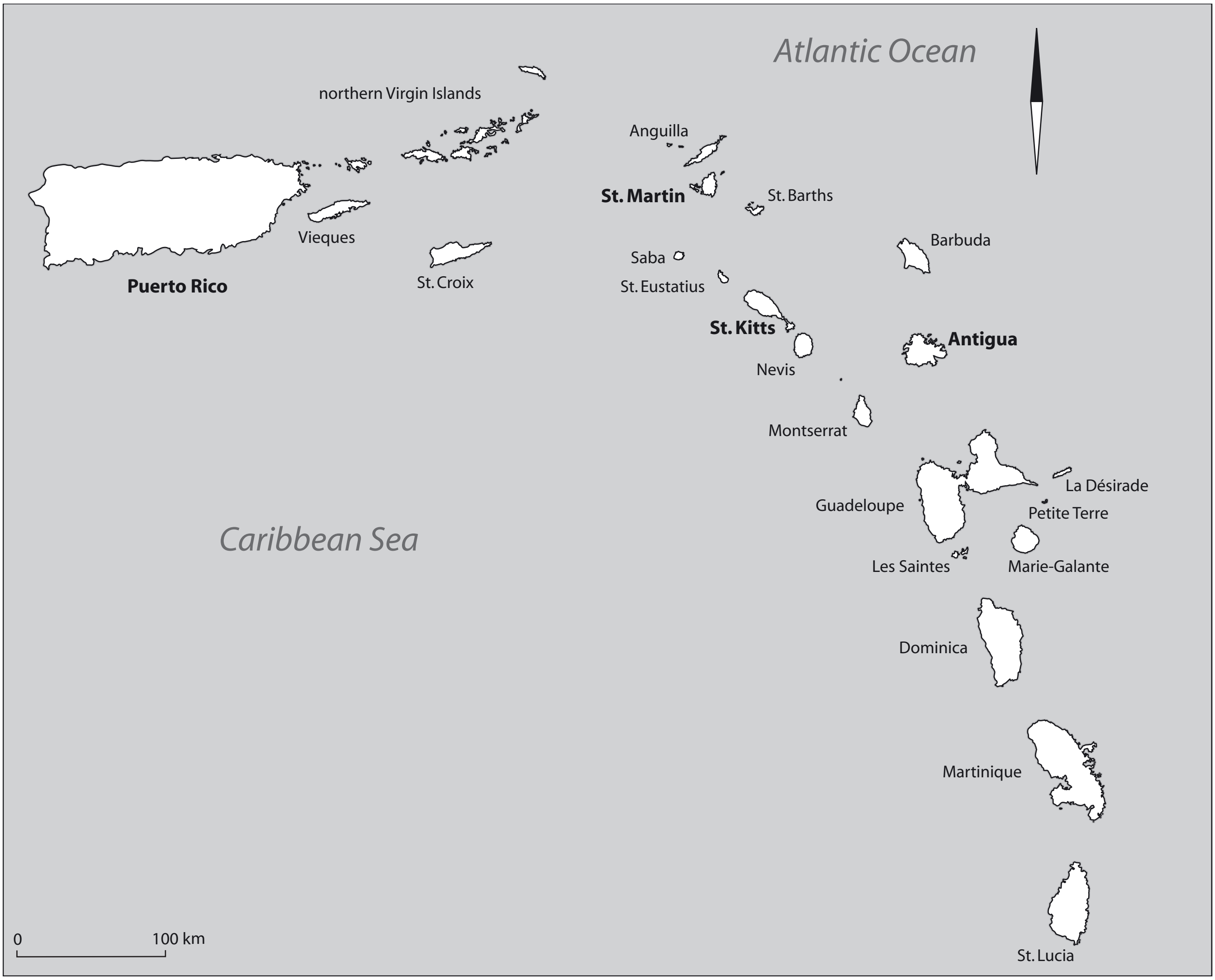

Figure 2.1. Map of the area studied in this work showing the source islands in bold.

fact that many of the sources are secondary surface scatters. It should be specified that only weathering of material on the sources themselves before acquisition is at issue here, that is, the weathering of geological material (see Lavin & Prothero 1992), and that the weathering of artefacts after manufacture is not dealt with. It is assumed that post-depositional weathering had not significantly altered the chemical composition of the manufactured material, given the short period of burial of the artefacts related to the Ceramic Age. Sheppard and Pavlish (1992), however, have presented an example to the contrary. In their case from the Pacific islands, the chert artefacts display a macroscopically identifiable change in their appearance, which has not occurred for the large majority of chert materials from Caribbean archaeological sites. Besides, the chemical changes of the Pacific artefacts can be mainly attributed to interaction with relatively extreme types of soils, such as bauxitic ones.

2.2.2 Chert nomenclature

Before I go into the methodology that was used during mapping of the chert sources, I need to clarify what I define to be chert and what considerations guided the choice to include specific chert sources in this research and not others. Chert generally is used as the overall name for micro- to crypto-crystalline varieties of sedimentary silica in the form of the most stable crystal variety quartz, often including minor amounts of less stable crystal varieties of opal and chalcedony (Luedtke 1992). According to Hauptmann (1980), this is a narrow definition, since it only includes sedimentary varieties of silica. In addition, crypto-crystalline silica varieties can also occur in volcanic rocks as inclusions or in hydro-thermally altered veins such as, for example, agate, jasper, or chalcedony (figure 2.2).

In relation to the sedimentary varieties of chert, geological handbooks generally distinguish two types of chert: nodular and bedded cherts (Blatt 1992; Nockolds *et al*. 1978; Pettijohn 1975). According to this distinction, flint is seen as variety of chert and used to denote the nodular cherts which form authigenically in limestone and that are usually dark in colour. Bedded cherts, on the other hand, display a range of colours. They comprise the pure silica deposits often formed in deep marine environments and found in proximity to volcanic formations. In many cases, they contain remnants of siliceous biogenic tests, such as radiolaria. These latter cherts can have different names such as, for example, novaculite or radiolarian chert (Blatt 1992; Luedtke 1992; Nockolds *et al*. 1978; Pettijohn 1975).[2]

Apart from these micro- to crypto-crystalline varieties of quartz, quartz can also occur as a macro crystal variety, often present as inclusions in igneous or metamorphic rock. In this case it is simply called (smoky) quartz, or amethyst, aventurine, citrine, and rose quartz, depending on its colour.

These distinctions are based on different geological contexts of formation, and often are difficult to recognize when one is only confronted with isolated rock specimen, as archaeologists generally are. Therefore, it should be noted that within archaeological literature name giving does not always bear a relation to geological origin, and that it may be the result of the use of folkloric names, or even may correspond to quality differences of the rock.[3]

In this thesis, I follow the broad geological distinction between sedimentary nodular and bedded cherts, and other non-sedimentary types of chert. I classify a siliceous piece of rock as flint when it has been formed authigenically in carbonate rock, usually in a nodular form.[4] For all bedded siliceous rocks, I use the term bedded chert. The more general term chert is reserved for all varieties of fine-crystalline siliceous rock, for which the geological relation to its formation is not specifically defined. For these, I sometimes use the term chalcedony to cover all opaque, fine-grained, often white, silica varieties, that do not contain any macroscopically visible biogenic clasts (fossils or fragments of fossils) or carbonate grains, so suggesting a possible non-biogenic origin. The use of the term chalcedony in this case should not be confused with the fibrous crystal variety, that can occur in most cherts, but which is only visible through microscopic study.

2.2.3 Cherts in the region

A large number of silica varieties, as specified above, occur in the Antilles and were used by the indigenous peoples over a long period. These include both macro as well as micro- to crypto-crystalline quartz rocks. This chapter, however, focuses on the micro- to crypto-crystalline varieties, as they were more specifically used for making flake tools, whereas the macro varieties were predominantly used for making lapidary artefacts, although exceptions occur.

Given the occurrence of a broad range of chert types within the Antilles (Bérard 1999; Bérard & Vernet 1997; Bodu 1984; De Mille 1995; Knippenberg 1997, 1999a; Murphy 1999; Pantel 1988; Pike & Pantel 1974; Walker 1980), a choice was made about which material varieties were to be included in the characterisation study and which were not. This choice was necessary to avoid having the series of source locations be too large, which would make success in petrographically or chemically distinguishing the different source types less probable. From a macroscopic analysis, it became clear that colour easily distinguishes the cherts into three general groups. Within these broad groups chert differs in appearance but is less easily distinguishable, especially for an untrained eye. These three groups are:

a) A multi-coloured group, including cherts ranging in colour from white, yellow, brown, grey to almost black. This group represents most of the chert varieties used within the northern Lesser Antilles, and therefore will be studied in this research. Cherts include flints, bedded cherts, other cherts, and silicified corals.

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2 Despite this general distinction, European geologists often use the word flint only for the nodular cherts from the Northwestern Cretaceous Chalk formations (Hauptmann 1980; Schmid 1986). This is a pure regional distinction and the flints from these formations do not differ in properties and genesis from other nodular cherts in carbonate host-rock elsewhere in the world.

3 Luedtke, for example, mentions the use of the name Knife River flint from North Dakota for a chert which actually is a silicified bedded lignite and not a nodular chert (Luedtke 1992, 124). In this respect the habit of many North American archaeologists to name high quality silica varieties “flint” and the poorer quality ones “chert” must be mentioned as well (Haviser, personal communication 1993).

4 Authigenic chert in carbonate rock can have a variety of forms, the most common one is in bands of nodules. Other forms are around burrows, or occasionally as thin beds or irregularly shaped concretions (Clayton 1986; Zijlstra 1994; Felder & Bosch 1998; Schins 1998).

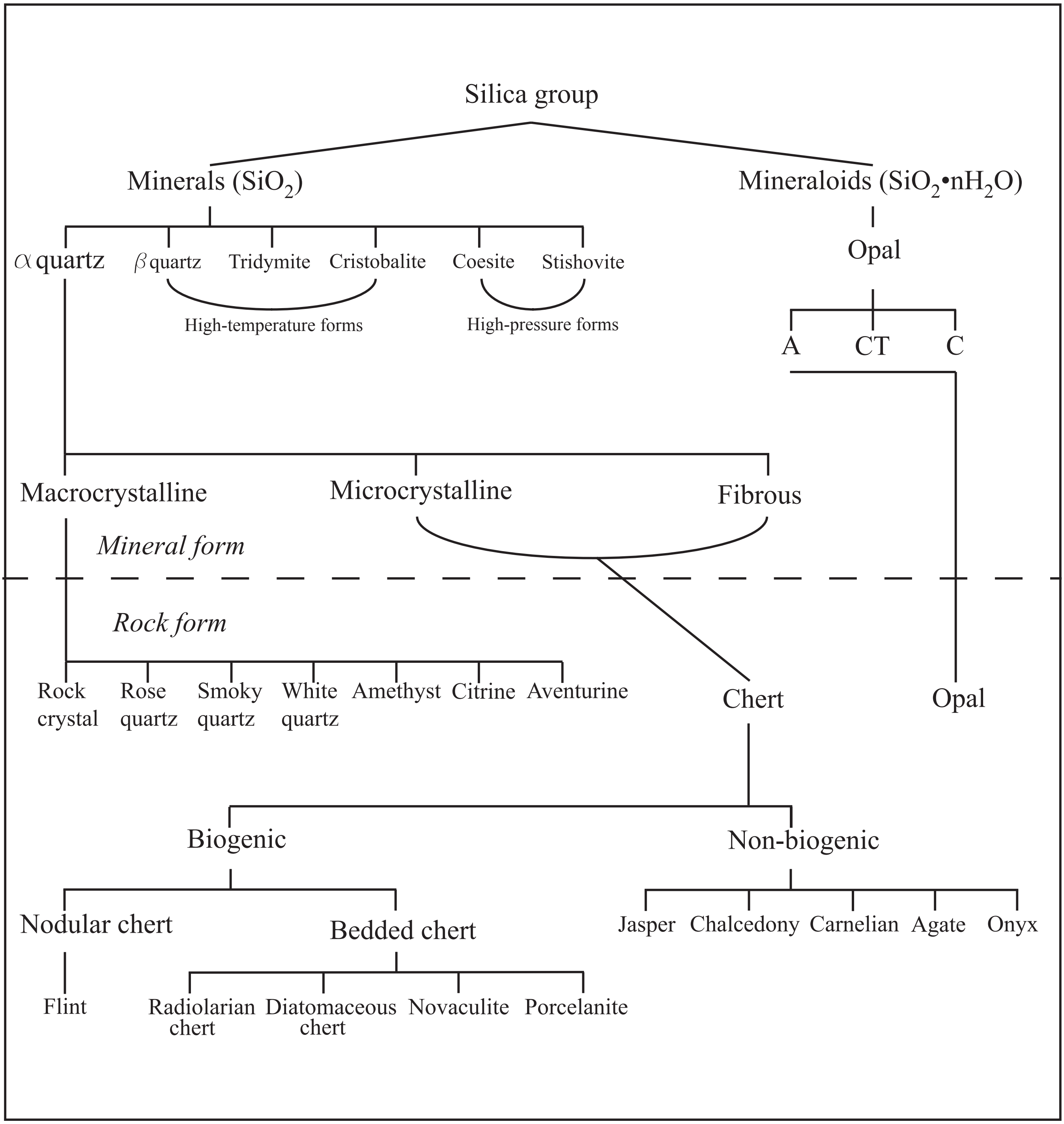


Figure 2.2. Relationship between silica minerals and related rock varieties (based on Leudtke 1992 with modifications).

b) A green-coloured group, including light to dark grey-green varieties. This group of cherts is rare among flaked material within the northern Lesser Antilles. It predominantly can be found at Puerto Rican sites (Rodríguez Ramos 2001a; see Chapter 5). The only known source locality thus far is the bedded chert from the Mariquita Chert Formation in southwest Puerto Rico (Volckmann 1984a,b).

c) A red-coloured group. This group of cherts is rare as well among flaked material from northwestern Lesser Antilles sites, although more frequently occurring than the green cherts. On Martinique, however, local red jasper was the most widely used material on the island (Bérard 1997). Other sources include a red radiolarian bedded chert on La Désirade (Bodu 1985; Bouysse *et al.* 1983; De Waal 1999a; Montgomery *et al.* 1992), jasper on St. Martin (Christman 1953), and bedded cherts within the eastern part of Puerto Rico (Rodríguez Ramos, personal communication 2000).

In addition to these three colour groups, some clear petrographically distinguishable varieties of chert can be picked out beforehand. These include, for example, a white and translucent macro-crystal variety of quartz, which behaved differently during flaking than the cherts, as well as petrified wood, which still has its very characteristic wood structure preserved.

2.2.4 Methodology of the characterisation study

Mapping of sources and sample taking

Focussing on the multi-coloured group meant that basically three islands are of interest. These islands have chert occurrences that might have functioned as source locations for the materials used by the Amerindians in the surrounding region. These islands include the following ones:

1) Antigua, where the Long Island source is situated (Nicholson 1974; Olson 1973; Van Gijn 1989), as well as other flint and (bedded) chert occurrences (Martin-Kaye 1959; Watters & Donahue 1990; Weiss 1994).
2) St. Kitts, where archaeological work by Arizona State University identified several natural surface scatters of flint (Walker 1980, 1981).
3) The southwest area of Puerto Rico near Cabo Rojo, where the existence of chert sources has become known during the past decennia (Pantel 1988; Pike & Pantel 1974).

Based on my previous research aimed at sourcing of flint and chert in the region (Knippenberg 1995, 1997, 1999a), the island of Antigua and in particular the Long island flint source is believed to be the most important locality where material was obtained. This prior knowledge guided to a certain extent my search and mapping of unknown sources. Given the existence of high quality flint within the limestone district of Antigua, major attention was dedicated to this part of the island. In addition to reported and known flint localities, rock sections along the eastern and western coasts where inspected to search for unknown flint nodule bands. Within the other parts of Antigua, as well as the islands of St. Kitts and Puerto Rico, only reported and known localities were visited. These were considered to be possible source areas where material might have been obtained during pre-Columbian times. In addition, some present-day quarries were visited and sampled as well, but only if they were believed to provide additional information regarding the chert characterisation.

In the characterisation of chert material attention was devoted to the relation of the chert with its environment during its formation. I tried in the field to identify the type of host-rock, where chert was formed, as it is believed that the type of host-rock in large part determines variability in the chert's characteristics. However, the relation with its environment of formation was not always straight forward and this, became clear when analysing the numerous secondary chert scatters in Puerto Rico (see below).

At each location, samples were taken from all possible contexts, that is, from original layers, bands or nodules still preserved in rock sections (primary context), from natural surface scatters (secondary context) as well as from work-shop sites or flaked scatters of material in the source area (tertiary context). In many cases, it appeared that only the secondary context was present. Collection of rock samples occurred haphazardly, during which textural variation, as well as variation in clast content (particles such as fossils or remnants of carbonate in the matrix) and colour of the chert material were taken in consideration. Only in a few instances more systematic sample collection was performed. This usually occurred if material was still available in a primary context, allowing the possibility of taking several samples from one layer at certain distances or to sample different layers present.

Rock samples were initially described macroscopically on the following features: (a) colour, (b) type of cortex, (c) presence of clasts, (d) lustre, (e) grain size, and (f) texture.

Characterising cherts
Similar to characterisation studies performed on cherts in other parts of the world (see Church 1994 for overview), that searched for methods more objective than common macroscopic classification, this study made use of geochemical techniques. The use of macroscopic analysis, which is still widely applied in chert sourcing, was considered to be a poor option in this particular case. This is because of the significant variation in the macroscopic appearance of samples within a single source, as a result of the secondary nature of many of them. Apparently weathering had significantly altered many of the rocks macroscopically, making it difficult even for the trained eye to classify individual artefacts.[5]

Following work by Kars *et al*. (Kars *et al*. 1990; see Thompson 1986) and continuing earlier research (Knippenberg 1995, 1997, 1999a), the determination of trace element composition using Inductively Coupled Atomic Emission Spectroscopy (ICPAES) was chosen as a promising method. This method allowed the determination of a number of different variables in the form of the trace-element concentrations, increasing the possibility of discrimination. Furthermore, actual sample preparation was relatively straightforward and not very time-consuming. A draw-back of the method included the destruction of the rock sample. I refer to the Appendix C for a more detailed description of sample preparation.

In addition to the chemical analysis using ICPAES, a number of samples from each source were thin-sectioned allowing microscopic analysis. These sections were studied to obtain a better understanding of the nature of the chert in question, and to link certain macroscopic and microscopic features with chemical characteristics.

Considering the aims outlined in paragraph 2.2.1, the following procedure was followed when taking samples for chemical analysis and microscopic analysis:

a) From the collection of chert rock specimens gathered during the different field-trips to the sources, a minimum of 8 samples per source were chosen, allowing statistical treatment of the data. In some cases, the final number of samples exceeded this initial standard number (see tables 2.5-9 for the total number of samples per source).

b) Samples were taken from, if available, a primary, secondary, and tertiary context. In case of secondary and tertiary scatters, attention was given to weathering of the rock by choosing additional samples.

c) The sample covered the full range of textures, colours, and clast contents encountered within a source.

d) A sub-sample, including at least 4 specimens per source, was prepared for thin-section study using the petrographic microscope.

e) In addition to the chert samples, a very limited number of samples from host-rock, if present, were chosen as well for chemical analysis. Generally, this number did not exceed one or two specimens per source.

Apart from these possible sources, present day-quarry sites or other localities where flint is exposed were sampled as well. This was primarily done to obtain a better understanding of chemical variation among cherts from similar host-rocks within similar formations.

2.3 Description of sources and related geology

2.3.1 Introduction

To understand more about the natural distribution of the chert varieties discussed in this research a short description of the geological history of the region is presented here. The Caribbean islands have been formed as a result of plate tectonics, more precisely as a result of the collision of the Atlantic and the Caribbean plates. Despite this general underlying cause of formation we encounter significant variation in evolution of the individual islands (Donavon & Jackson 1994; Weyl 1966). Basically, the Greater Antilles, including the Virgin Islands, can be grouped to the oldest land masses dating back to Upper Cretaceous or even Upper Jurassic, possessing a composite history of volcanism, marine sedimentation and metamorphism (figure 2.3) (Draper *et al*. 1994).[6]

The Lesser Antilles chain of islands is significantly younger than the Greater Antilles, generally not older than the

[5] As will be shown in the next chapter, lithic samples from settlement sites in the Lesser Antilles often consist of a variety of flint materials originating from different sources. This makes it necessary that individual pieces should be classified to sources, rather than whole samples being assumed to come from a single source.

[6] Considering this complex general geological history, during which the different Greater Antillean islands each experienced local variation as well, a discussion of this is left out. The primary focus is on the Lesser Antilles.

Eocene, and can be divided into two island arcs of volcanic origin (figure 2.4). An older outer arc extends from Anguilla in the north and moves along St. Martin, St. Barths, Barbuda, Antigua, and Grande Terre (Guadeloupe), to Marie Galante in the south, after which it joins the inner arc. This younger inner one, which lies to the southwest of its neighbour, signifies the present zone of convergence, where the Atlantic plate moves under the Caribbean plate. This arc includes the islands of Saba, St. Eustatius, St. Kitts, Nevis, Montserrat, Basse Terre (Guadeloupe), Dominica, Martinique, St. Lucia, St. Vincent, the Grenadines, and Grenada (Wadge 1994; Westermann 1957). The change of arc is thought to have taken place around 9 Ma and involved only the northern portion, while the southern part remained in place (Baker 1984). The inner arc islands are predominantly volcanic in nature, whereas the outer arc islands vary more in geological build-up. Most exhibit a composite nature of old arc-volcanics, non-carbonate marine deposition, as well as relatively large carbonate formations, that usually post-date the old arc-volcanism (Christman 1953; Westermann 1957; Martin-Kaye 1959; Weiss *et al*. 1986).

The islands of La Désirade, Barbados, Trinidad and Tobago do not belong to either of the arcs. The origin of La Désirade is still debated: it either represents an "ophiolitic complex," "an orogenic series," or "a primitive island arc fragment detached from the eastern Greater Antilles" (Montgomery *et al*. 1992). Trinidad and Tobago geologically form part of the South American mainland, and Barbados is "the exposed top of the accretionary wedge of sediments that have been scraped off by the subduction (of the Atlantic plate underneath the Caribbean one)" (Wadge 1994).

Chert and flint sources relevant to this study can be found on three islands, Antigua, St. Kitts, and the south-western part of Puerto Rico. These islands present totally different geological settings.

Antigua, lying in the northeastern corner of the Lesser Antilles, is one of the composite islands formed during old-arc volcanism. Basically, the island can be divided into three geological different regions (figure 2.5). The Basal Volcanic Suite covers the southwestern part of the island. It primarily consists of pyroclastic and igneous material of Oligocene age. The Central Plain group, also Oligocene in age, consists of stratified series of agglomerates, agglomerative tuffs, sandy tuffs, shaly rocks, and cherts (Martin-Kaye 1959), and covers the middle strip of the island, extending from the northwest to the southeast. The northeast part, including the many bays and islands, belongs to the Antigua Formation, an Oligocene series of limestone depositions, consisting of biomicrites, reef limestones, and limy mudstones (Weiss 1994).

St. Kitts is situated along the younger inner arc of the Lesser Antilles. It is a true volcanic island, with basically four regions of past and sub-recent volcanic activity (figure 2.6). The igneous rocks within the Southeast peninsula have been dated as the oldest rocks, around 2.3 Ma (Baker 1984). Later activity shifted towards the northeast, where the South East range and the Middle range centres are estimated to have erupted around 1-2 Ma. Mount Misery represents the area of lates activity, with still active fumaroles in its crater and a possible historic eruption in 1692 (Baker 1980). The volcanic rocks on the island mainly consist of pyroxene andesites, with smaller amounts of basalt and basaltic andesites.

In addition to these volcanic rocks, small limestone formations occur at several places on the island. The limestone at Brimstone Hill, on the leeward side, is best preserved and most extensive. This Brimstone Hill formation is considered to be a marine floor that has been uplifted by volcanic activity of the youngest centres. Its formation is dated prior to these eruptions but after the arising of volcanoes at the Southeast peninsula (Trenchmann 1932; Westermann & Kiel 1961). Other limestone occurrences on St. Kitts are reported at Goodwin gut and as small outcrops scattered over the island.

Puerto Rico can be geologically classified to the Greater Antilles Orogenic Belt, a geological region that includes the Virgin Islands, a major part of Hispaniola and the southeastern end of Cuba as well (Draper *et al*. 1994). Its history of formation presents a long succession of volcanic, intrusive, metamorphic, sedimentary and tectonic processes (Larue 1994). Recently, Larue (1994, 161) presented a general summary of the island's geological history based on an extensive series of earlier work. He has listed 9 important phases and has divided the island into several zones (figure 2.7). The oldest rocks, dating to the late Jurassic present old oceanic crustal development. This is followed in the early Cretaceous by the first island arc volcanism. This arc is considered to be the ancestral arc of the Caribbean region and predates the Lesser Antillean ones. Arc build-up, interrupted by two phases, continued until the late Eocene, after which a period of uplift, deformation and rotation lasted until the middle Oligocene. Significant carbonate platform development occurred from the late Oligocene to Miocene, and the last phase is characterised by a series of tectonic rotational events.

The region where most chert occurrences are formed, is called the Southwest block. This block is part of the whole middle range of the island, which exposes rocks related to the crustal development and island arc volcanism events. Within the Southwest block, the oldest rock formations are found in the Bermeja complex, "a serpentinite melange consisting of dismembered ocean floor (including cherts) and island arc derivatives such as volcanic and volcaniclastic rocks" (Larue

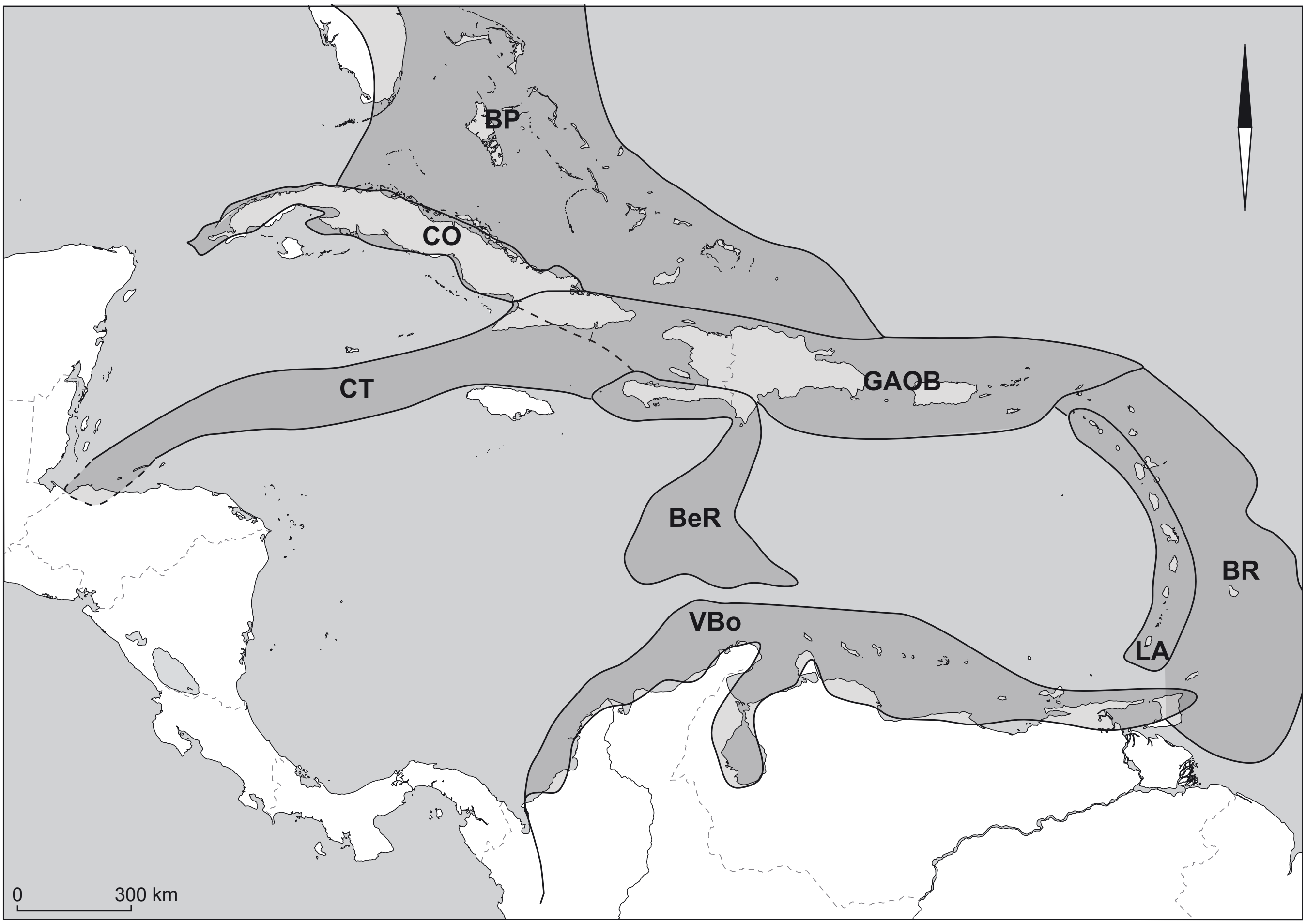


Figure 2.3. Map of the Caribbean region showing some of the geological provinces (redrawn after Draper *et al.* 1994, fig. 1.1 and based on Case and Dengo 1982; Case *et al.* 1990). BeR = Beata ridge; BP = Bahamas platform; BR = Barbados ridge and Lesser Antilles deformed belt; CO = Cuban Orogenic belt; CT = Cayman trough; GAOB = Greater Antilles Orogenic belt; LA = Lesser Antilles; VBo = Venezuelan borderland.

1994, 156). This region includes major occurrences of bedded chert grouped within the Mariquita Chert Formation. Two major limestone facies originate in a later period.

2.3.2 Chert sources

Field-walking of potential source areas, close reading of geological and archaeological reports, and consulting with local archaeologists has resulted in the identification of 15 potential source locations from where Amerindians may have acquired material for stone tool production in the overall study area. These locations either have remains of prehistoric exploitation in the form of scatters of flakes, blades and cores, or still bear chert in host-rock, which must have been available to the indigenous inhabitants. The reader is referred to Appendix A for a more detailed description of each source individually. In addition to these 15 sources, one location at Hughes Bay along Antigua's northeastern coast, where flint was found, probably represents an artificial flint occurrence, the result of stone ballast droppings during historical times (see figure 2.5; see Appendix B). Furthermore, at another three locations on Antigua, chert and flint material was also identified, inspected and sampled. At these locations chert and flint is exposed as a result of contemporary stone quarrying or house construction and therefore these localities should not be considered as potential prehistoric source areas.

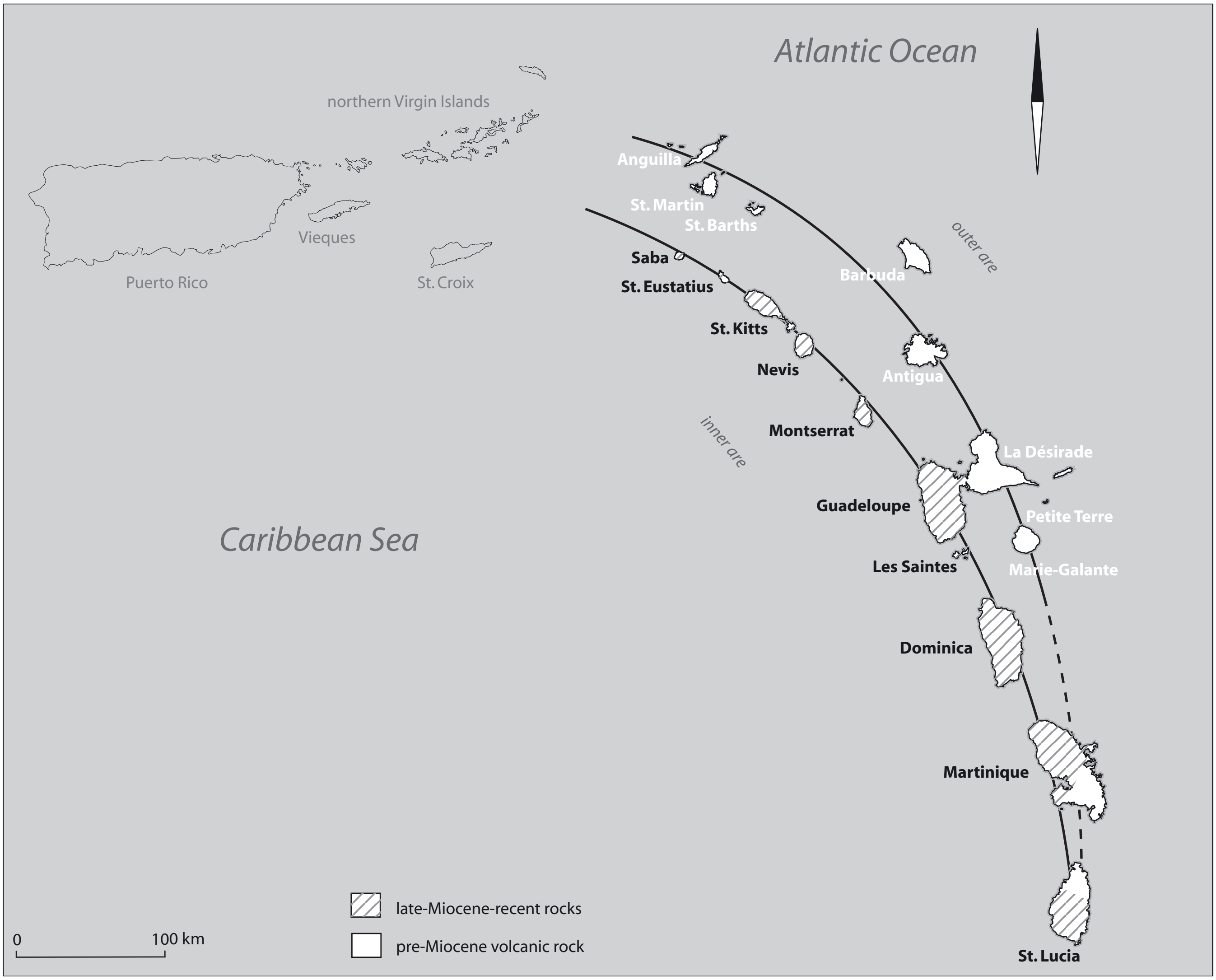


Figure 2.4. Map of the Lesser Antilles inner and outer volcanic arcs (redrawn after Multer *et al.* 1986, fig. 1.1).

Table 2.1 lists all 15 sources. It is immediately noticed that the majority are found on Antigua (see figure 2.5). Five localities geologically form part of the Antigua Formation, the extensive limestone formation covering the northeastern part of the island. Two are associated with tuff deposits from the Central Plain Group, and one is found among tuffs belonging to the Basal Volcanic Suite. It should be pointed out that for all these sources a clear association with their direct geological surroundings can be established: the sources either represent primary occurrences, where chert or flint still can be found in its rock of formation, or they represent secondary sources where a relation with its direct surroundings can be established on basis of material characteristics. This contrasts to the sources found on St. Kitts, as well as those in the southwestern part of Puerto Rico, where such relation proves more difficult to ascertain (see below).

As outlined above the Antigua flint sources in this region are considered to have been of primary importance to the Amerindians. Therefore, rock sections exposed along the eastern and western shores were inspected, as well as modern inland quarry sites in search of unreported flint occurrences, to gain a better understanding of the stratigraphy of the Antigua Formation and in particular, the stratigraphical position of the flint bearing layers in this formation (figures 2.5, 2.8-11). Inspection of a large section at the contemporary Piggott's Hill quarry site, which reveals a significant part of the stratigraphy of the Antigua Formation, shows that the flint bearing limestone layers are very restricted and that basically one deposit, which consists of fine-grained calcareous mudstone, contains nodule layers (see figure 2.11). The idea of restricted

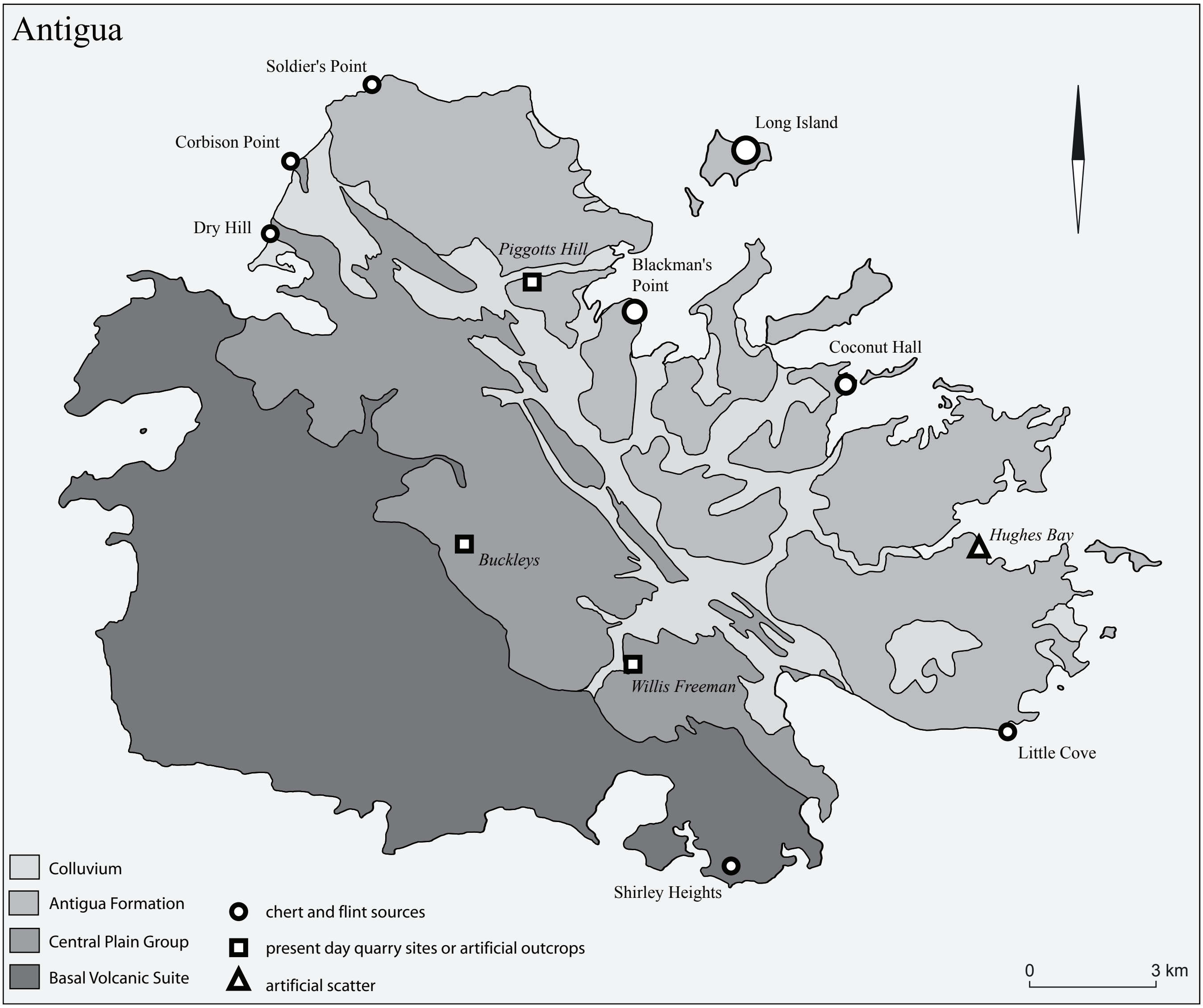


Figure 2.5: Geological map of Antigua showing the three main geological regions and the location of flint and chert sources, including the location of the artificial flint scatter at Hughes Bay, the limestone present day quarry site at Piggotts Hill, and chert outcrops at Buckleys and Willis Freeman (geological map based on Multer *et al.* 1986, fig. 2.1).

occurrence is also supported by the absence of flint within the many sections inspected along the eastern and western coasts.

During the survey a recurrent stratigraphy emerged, which was applicable to the different flint bearing rock sections. In short, it can be said that calcareous packstones, with high concentrations of foraminifers and usually indicating relatively high energy circumstances of deposition, underlie the flint bearing limestone layer. This latter layer generally consists of calcareous mud- or wackstones, which were deposited in a low energy environment. The number of flint nodule layers generally does not surpasses three. On top of this deposit reef limestones formed during relative high energy deposition.

Based on this stratigraphy, Hans Zijlstra (personal communication 2000) formulated a possible explanation for the rare occurrence of the flint bearing limestone layers, restricted to the middle of the Antigua Formation. He noted that the Antigua Formation is an Oligocene rhythmically bedded transgressive-regressive succession, reflecting an initial flooding of a steep, rapidly subsiding volcanic island, followed by a gradual shallowing again, due to decrease of subsidence rate and sediment deposition at the island margins. During this evolution, coral reefs moved from the coast seawards and back to the

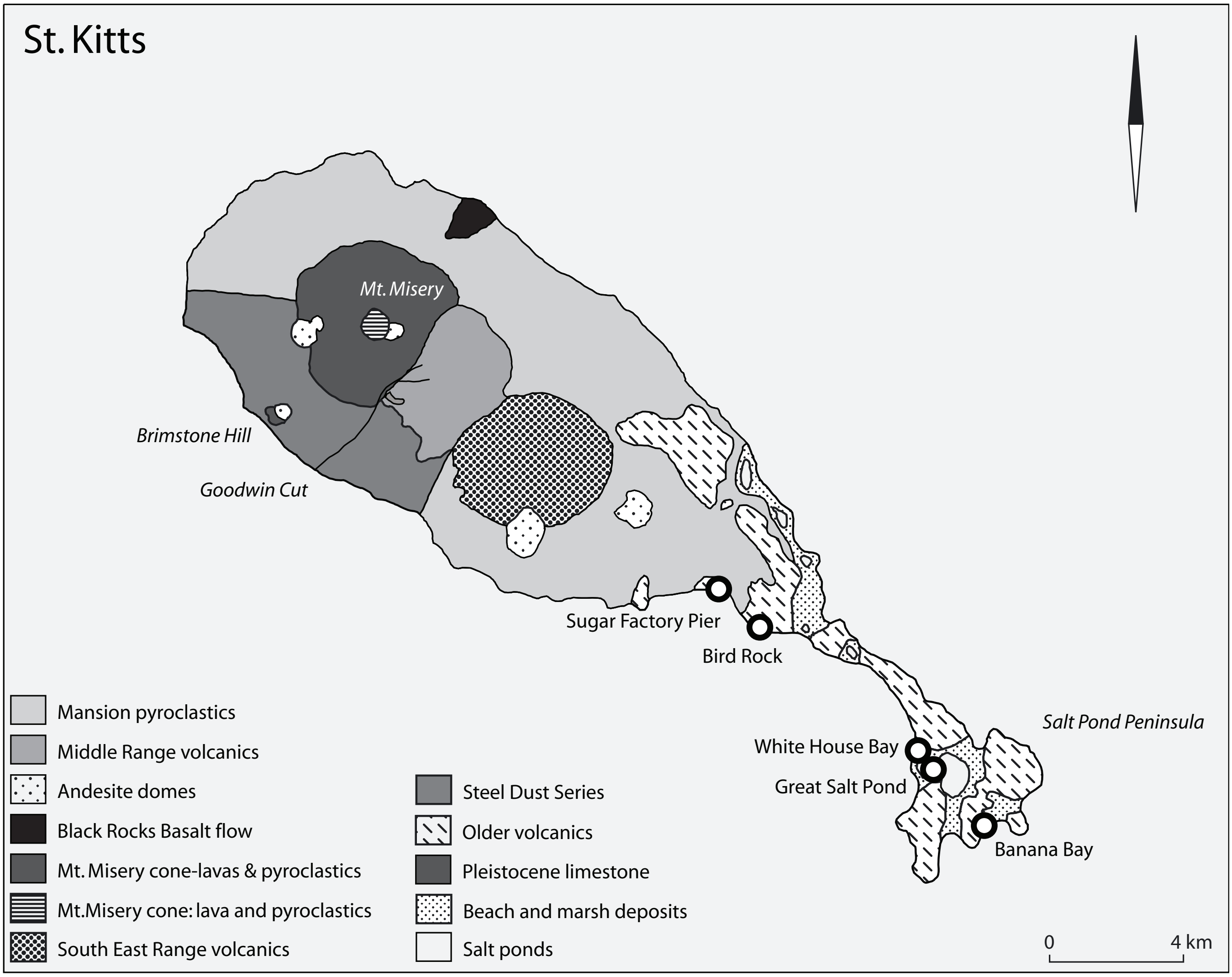


Figure 2.6. Geological map of St. Kitts, showing the location of flint scatters (geological map based on Baker 1968, fig.1).

coast again, forming an opening and closing restricted lagoon between land and open sea. As flint nodule layer genesis is understood to occur during conditions of rather low water energy in combination with relatively low deposition rate (Zijlstra 1994), only during the maximum extension of the lagoon, siliceous opal-rich flint layers should have been formed and preserved, allowing the much later genesis of flint nodule layers, probably during a Pleistocene sea-level fall.

The inspection of the Piggots Hill quarry rock section revealed a thin clay layer only 1 m below the flint bearing limestone layers, which had a high concentration of detrital quartz grains. It may be that this clay layer is another proof for relatively low deposition rates of carbonates and concentration (condensation) of quartz grains, constantly swept in from land by wind or water. Alternatively, the flint and clay layers in the middle of the Antigua Formation may reflect a period of excessive influx of siliceous material from land, either deposited directly or after uptake by biogenic opal producers.

In any case, it is suggested that the flint nodule layers have a very restricted occurrence in the stratigraphic succession and therefore, a detailed knowledge of the stratigraphy of the Antigua Formation enables the recognition of areas where flint is likely to be exposed, and were sources can be found.

The Central Plain Group and the Basal Volcanic suite represent the other two geological regions on the island of Antigua. Both pre-date the Antigua Formation, but are also Oligocene in age. The Basal Volcanic suite was formed by

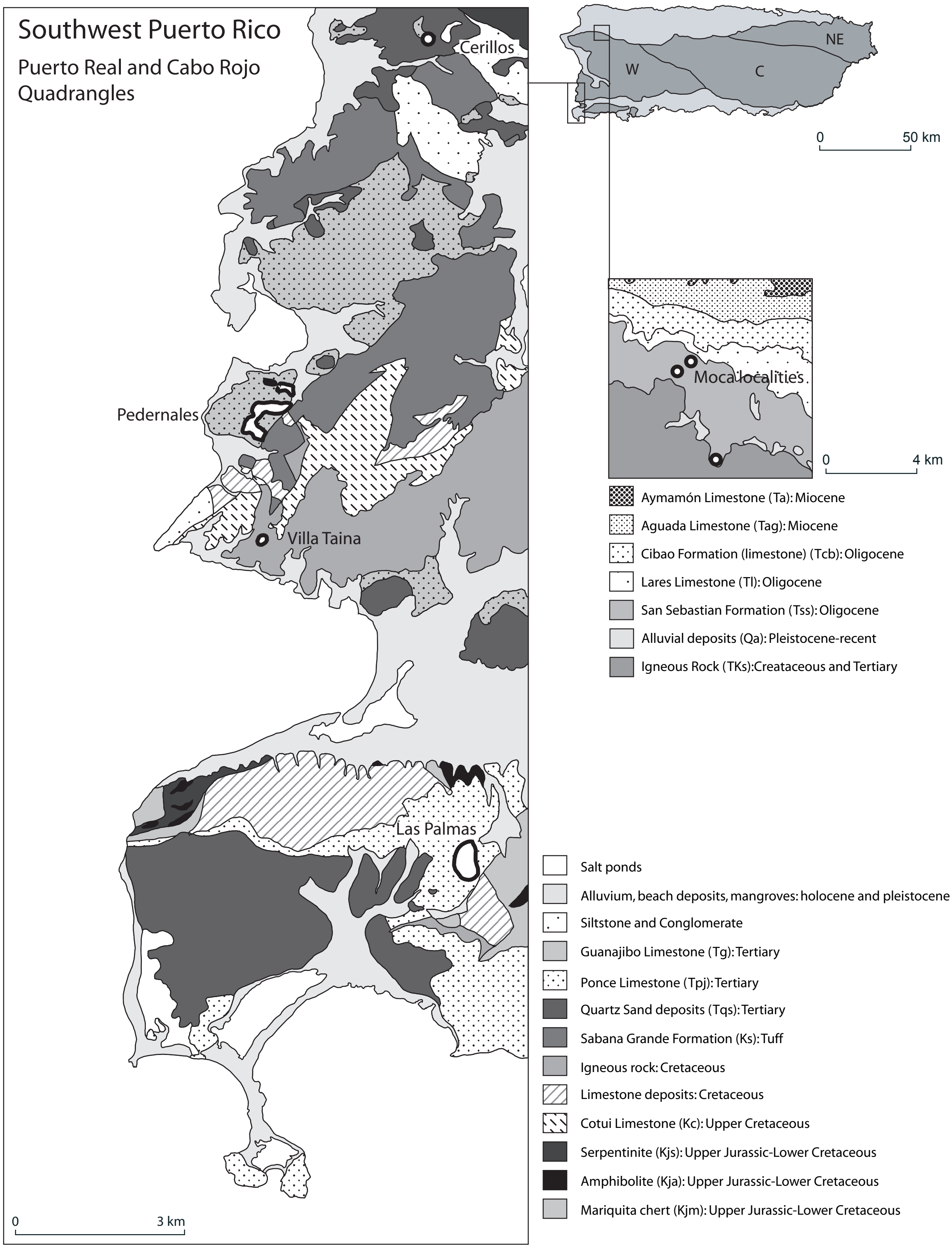


Figure 2.7. Geological map of the southwestern part of Puerto Rico showing the location of chert sources in white (geological map based on Volckman 1984a,b).

Island	Source Locality	Geological setting	Type of (original) hostrock	Type of occurrence	Description
Antigua	Long Island (LI)	Antigua Formation	Limestone	primary, secondary, tertiary	Major flint occurrence on small island off Antigua's northern coast. Flint is scattered along the islet's northern shore and at surface scatters on large portions of the island.
	Little Cove (LC)	Antigua Formation	Limestone	primary, secondary	Limestone section and cobble beach along Antigua's eastern coast. Flint can be found on the cobble beach and in limestone sections
	Soldier Point (SP)	Antigua Formation	Limestone	primary, secondary	Extended rock point along Antigua's northwestern coast. Flint can be found within limestone of this rock point as well as at both cobble beaches enclosing it.
	Blackman's Point (BP)	Antigua Formation	Limestone	secondary, tertiary	Exclusive secondary occurrence of flint at the Blackman's Point peninsula along Antigua's northern shore. Flint can be found scattered on the surface and along an eroded coast-line.
	Coconut Hall (CH)	Antigua Formation	Limestone	secondary, tertiary	Exclusive secondary occurrence of inland scatters of flint at Coconut Hall along Antigua's northern coast.
	Shirley Heights (SH)	Basal Volcanic Suite	Tuff	primary, secondary	Chert boulders are exposed at the flanks of Shirley Heights in the southeastern part of Antigua, surrounded by secondary surface scatters.
	Corbison Point (CP)	Central Plain group	Tuff	primary, secondary	Bedded chert layers exposed at a rock-point along Antigua's northwestern coast. Secondary chert is lying on the adjacent cobble beach.
	Dry Hill (DH)	Central Plain group	Tuff	primary, secondary	Bedded chert layers exposed at a rock-section along Antigua's northwestern coast, secondary chert is lying on the adjacent cobble beach.
St. Kitts	Great Salt Pond (GSP)	Unknown	Limestone	secondary	Secondary surface scatter of small cobbles situated along an artificial dam separating two salt lakes in the southwest peninsula of St. Kitts.
	Sugar Factory Pier (SFP)	Unknown	Limestone	secondary	Small cobbles scattered on a cobble beach predominantly consisting of igneous rock, along St. Kitts southern shore near the capital of Basse Terre.
Puerto Rico	Cerrillos (CE)	Guanajibo Formation	Limestone	secondary, tertiary	Significantly destroyed inland surface scatter near the village of Conde Avila within the southwestern part of Puerto Rico.
	Pedernales (PE)	Guanajibo Formation	Limestone	secondary	Extensive inland surface scatter of relatively large irregularly chert boulders in the immediate surroundings of the village of El Cerro in the southwestern part of Puerto Rico.
	Las Palmas (LP)	Ponce Formation Mariquita Chert	Limestone Chert	secondary, tertiary	Extensive inland surface scatter near the village of Las Palmas in the southwestern part of Puerto Rico. The surface scatter includes secondary green chert material from the Mariquita Chert Formation as well.
	Villa Taina (VT)	Cotui Fromation	Limestone	secondary	Small inland surface scatter of relatively large irregularly shaped chert boulders 2.5 km west to the village of Boqueron in the southwestern part of Puerto Rico.
	Moca (MO)	San Sebastián Formation	Conglomerrate	secondary, tertiary	Inland surface scatters of chert within the valley of the Culebrinans river in the western part of Puerto Rico.

Table 2.1. Description of chert and flint sources within the northern Lesser Antilles and Puerto Rico, included within this study. Note that primary stands for chert or flint material still present in its original host-rock, secondary for eroded material out of the host-rock and tertiary for evidence of exploitation or working of the material at the locality in the form of scatters of flaked stone.

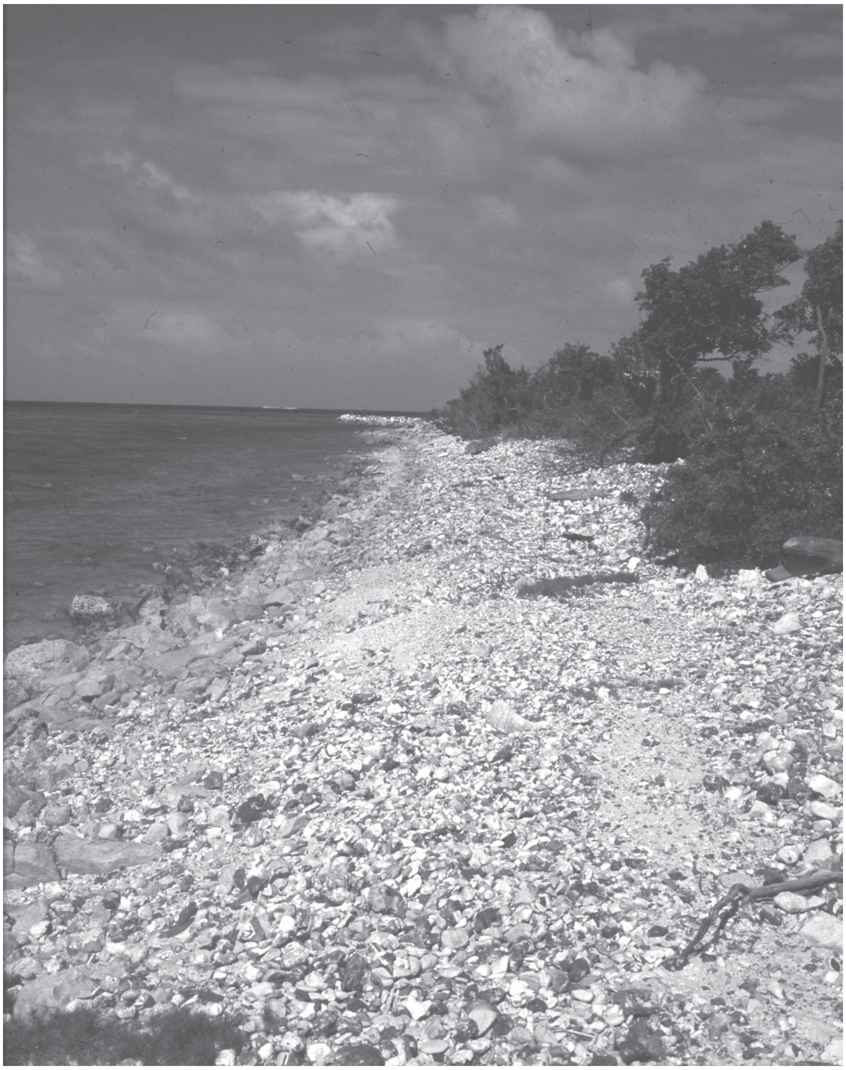


Figure 2.8. The Flinty Bay cobble beach along Long Island's northern coast.

predominantly calc-alkaline igneous rocks, with smaller volumes of limestone and other sedimentary rocks such as tuffs, tuffaceous mudstone, smectite and chlorite mudstone, and clay stone (Weiss 1994, 4). This area of the island either represents "the northeastern quadrant of a once-giant volcano that is now mostly blown away or eroded, and also drowned" (Weiss 1994, 4; see also Multer *et al*. 1986), or "the flank of the rising edge of the Caribbean plate" (Weiss 1994, 4; see also Mascle & Westercamp 1983).

The Central Plain Group consists of a thick sequence of mixed marine and non-marine rocks of both sedimentary and volcanoclastic origin, which extends itself across the island from the northwest to the southeast (Weiss 1994, 5). Rock materials include limestones, cherts, shales (marine), mudstones, arenite, tuff, and conglomerate (non-marine) (Weiss 1994, 5). Both regions contain occurrences of chert. In particular the Central Plain Group hosts different types of chert, of which extensive beds are most common, but also nodule shaped cherts, ranging from the size of golf-balls to that of soccer balls are present (Martin-Kaye 1959; Multer *et al*. 1986).

During my fieldwork, no attempt was made to locate additional sources, as this would require an enormous amount of field-walking. Therefore, I relied on the observations of Martin-Kaye (1959) and Weiss (1994), as well as from personal communication with Reg Murphy (1997). The occurrences sampled include Shirley Heights, Dry Hill, Corbison Point, Buckleys, and Willis Freeman (figures 2.12 and 2.13). At the latter two localities present day building and quarry activities expose chert, making it unlikely that Amerindians had used these specific materials. Future research should attempt to locate

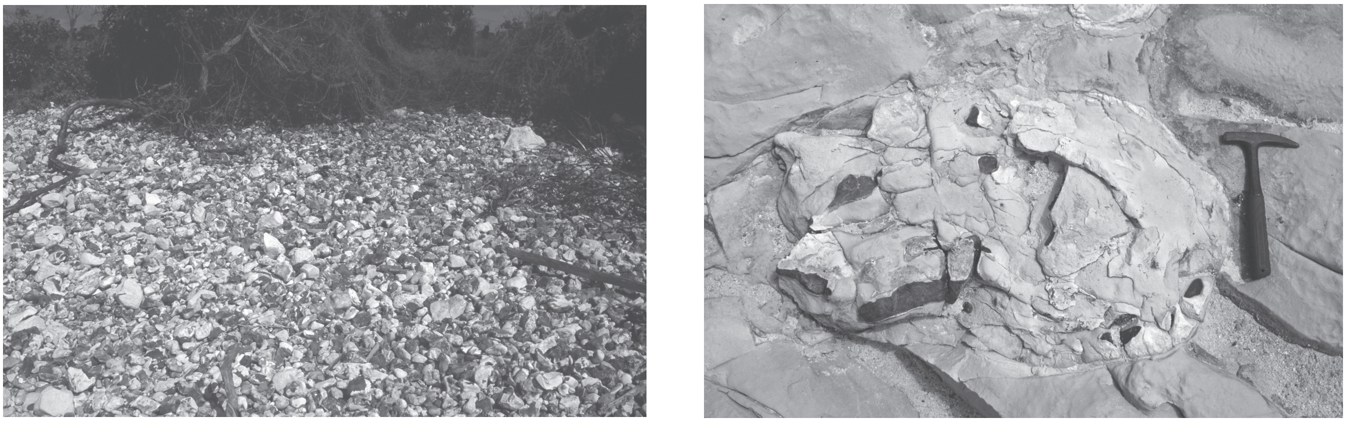
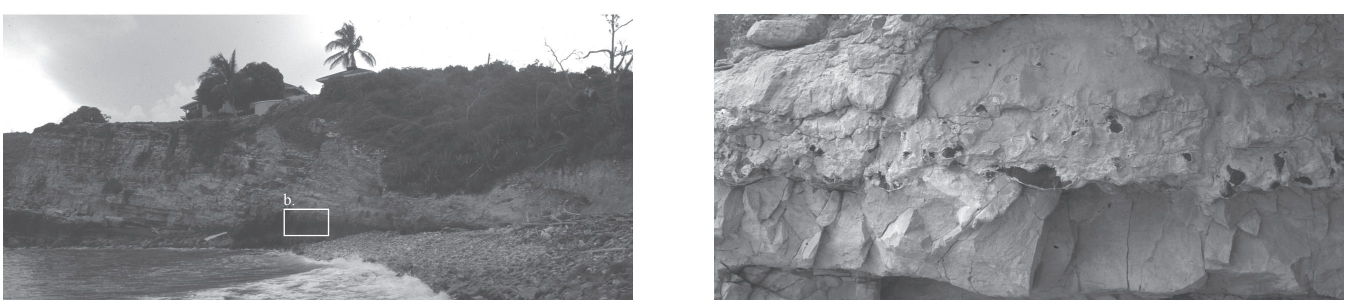


Figure 2.9. Flint cobbles rich area along Flinty Bay (left) and primary flint outcrop at Flinty Bay with cylindrical flint formed around a burrow of *Bathichnus paramoudrea* (right).

natural outcrops as well as possible archaeological evidence of exploitation, as Weiss (1994) reports natural outcrops of chert in both areas.

The presence of flint (limestone chert) on St. Kitts, which is predominantly a volcanic island, is odd and raises many questions. In total five flint occurrences were reported after research by the Arizona State University (see figure 2.6) (Armstrong 1978; Walker 1980, 64). All are secondary occurrences of flint pebbles found in areas where the older volcanics of the Southeast peninsula surface. Flint can be picked up scattered along igneous rock beaches at White House Bay, Banana Bay, and Sugar Factory Pier, below a rock cliff at Bird Rock, or on an artificial dam that has been erected to divide two salt ponds at Great Salt Pond. I only took samples at Sugar Factory Pier and Great Salt Pond.

In Appendix A, I go into more detail on this unexpected relation. From this evaluation it can be concluded that the flint scatters on St. Kitts actually are not likely natural to the island. The inability to identify its geological origin on the island and the possibly rare occurrence of St. Kitts flints within the archaeological record form the main arguments for this hypothesis. Similar to Hughes Bay on Antigua, a historic dropping as ballast load may be a possibility. Still, I am not able to find definite proof for an artificial occurrence and therefore these flint sources remain included within the following study (see figure 2.6).



a b

Figure 2.10. The Little Cove Bay (a) along Antigua's eastern coast, viewing the limestone section exposing flint nodule layers (b). Note that cobble beach primarily consists of flint pebbles.

a b

Figure 2.11. The limestone section exposed at the contemporaneous limestone quarry site at Piggots Hill (a), with a close-up of the section exposing rarely formed flint nodule layers, indicated by arrow in figure b.

On Puerto Rico, we are faced with another problem regarding the geological understanding of the sources. All sources are secondary in nature, that is, they only represent surface scatters of material (figure 2.14). For two sources, Cerrillos and Las Palmas, Volckmann (1984b, personal communication cited in Ortiz 1976) provides a possible geological relation, but it proved to be difficult to confirm this relation. In most cases, scatters of material are either lying in a limestone region or limestone formations are situated close-by. This suggests that the cherts should be considered as flints, i.e. formed in limestone. However, the structural absence of bioclasts and calcite indicate that these cherts are not flints in which quartz has replaced the original carbonate. They are more similar to the non-fossiliferous tuff cherts found on Antigua. Tuff rock, however, does not occur within vicinity to the chert localities, making this relation very unlikely. Another possible origin may be the formation of cherts in karstic carbonate rock (Thiry & Ribet 1999). In such a case the chert does not represent a replacement, as with flints, but is an infilling of original voids present in the limestone. This would entail that the final chert does not contain any fossils. This may also explain the presence of differently silicified veins and areas in the flint. These should be seen as incompletely silicified areas during first silification, after which they became silicified during a second phase. Still the data at present are inconclusive to fully understand the formation and presence of chert at these different localities. Future research should focus on the identification of any primary deposits of chert in or near the vicinity of the different scatters.

a b

Figure 2.12. Rock section at Corbison point exposing less eroded chert layers within tuff deposits (a), with a close-up of one of these chert layers (b).

Figure 2.13. Chert outcrops at Shirley Heights (a) with a close-up of one of these chert outcrops (b).

Macroscopic and microscopic characteristics

The macroscopic and microscopic study of the different cherts and flints provides a first basis for explaining the variability between and within sources. Furthermore, it contributes to the understanding of the trace-element composition, discussed within the next sections. Tables 2.2 and 2.3 list the most important macro- as well as microscopic features of the cherts and flints for each source separately. The reader is again referred to Appendix A for a more detailed description of material characteristics per source. The photographs in figures 2.15-17 present an overview of the microscopic textures of the different flints and cherts.

Summarising the macroscopic comparison between and within the sources, it can be concluded that intra-source variability generally is high, apart from a few exceptions. This high variability can for the most part be attributed to the secondary nature of all sources, where chemical weathering has altered the original appearance significantly. This is particularly evident in the wide range of colours, predominantly of a (light) brown and reddish brown hue among many source varieties. On a microscopic level, intra-source variability is less significant, although weathering has also contributed to some intra-source differentiation. Still, on this level, cherts and flints from related geological settings exhibit similar features. This suggests that source groups comprising geologically related sources can be distinguished in most cases.

Taking a closer look at the macroscopic characteristics, it is noted that the primary flint varieties in Antigua display strong similarities. In particular, primary flint nodules at Soldier Point and Little Cove, as well as at the contemporary quarry site of Piggots Hill possess a similar colour, grain-size, and clast-contents. Primary flint at the related source of Long Island

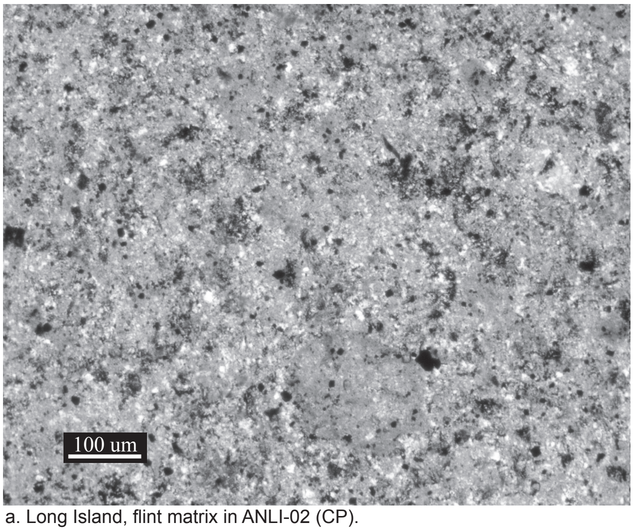
Figure 2.14. Overview of the natural chert scatter at Las Palmas, Puerto Rico.

Island and geological setting	Source	Colour	grain-size	fossils and other clasts	remarks
Antigua *(Antigua Formation)* *(primary)*	Long Island	* primary: very dark grey * secondary: (yellowish) brown - greyish brown	very fine	* haze of fine white calsts * rarely visible fossils	large range of colours
	Little Cove	* primary: (dark) brown - (dark) grey * secondary: (pale) brown - greyish brown	fine	* low concentration of fossils	
	Soldier Point	(dark) greyish brown - (pale) brown	fine	* low concentration of fossils	
(secondary)	Blackman's Point	1:light to dark grey (yellowish) brown, pale yellow light brownish grey 2:pink, reddish brown, weak/pale red	fine to moderate	* varied concentration of fossils	large range of colours
	Coconut Hall	1:dark greyish brown to pale brown 2: yellowish brown to light grey 3: grey to white	fine to moderate	* varied concentration of fossils	large range of colours
Antigua *(Basal Volcanic Suite)*	Shirley Heights	(light) grey to white	fine	* absent	
Antigua *(Central Plain group)*	Corbison Point	* primary: (very) dark grey * secondary: grey – pinkish grey – white	fine to moderate	* varied concentration of fossils	variation by bed
	Dry Hill	(very) dark grey – grey – (light) greyish brown	fine to moderate	* varied concentration of fossils	variation by bed
St. Kitts *(unknown geological origin)*	Great Salt Pond and Sugar Factory Pier	1: black – dark grey – greyish brown – olive brown – yellowish brown - brownish yellow 2: (light) grey – light brownish grey	very fine	* fossils rarely visible	*slightly translucent * large light coloured areas
Puerto Rico *(Guanajibo Formation)*	Cerrillos	(pale) brown – yellowish brown – (light grey) - white red	fine to moderate	* no fossils * iron oxides * rare round clasts (chalcedony)	veined rock
	Pedernales	brown – brownish grey – grey – white	fine to moderate	* no fossils	veined rock
Puerto Rico *(Ponce Formation)*	Las Palmas	* pale brown – greyish brown – grey – white * dark grey * yellow * white pinkish/red	fine to moderate	* no fossils * iron oxides	* large range of colours * varied textures veined rock
Puerto Rico *(Cotui Formation)*	Villa Taina	greyish brown – (light) grey – white	moderate	* no fossils	*veined rock
Puerto Rico *(San Sebastián Formation)*	Moca	brown – yellowish brown – white	fine to moderate	* no fossils	clastic texture

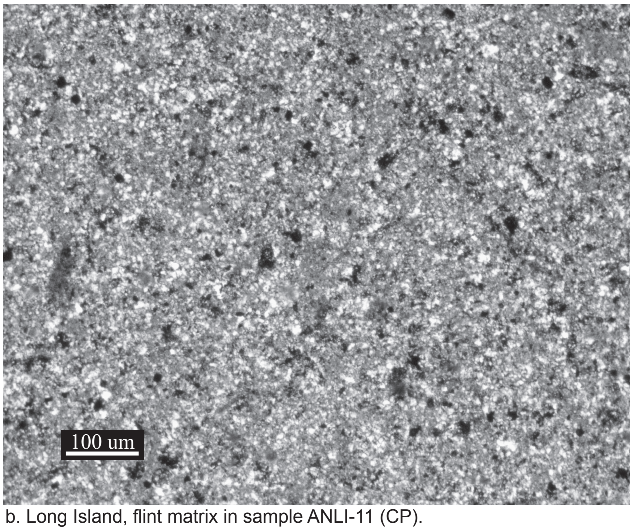
Table 2.2. Macroscopic characteristics of flint and chert by source.

Island and geological setting	Source	N	crypto-crystalline quartz matrix	carbonate	fossils	detrital minerals	other inclusions
Antigua *(Antigua Formation)* *(primary)*	Long Island	15	homogeneous fine size with larger crystals	* varied concentration of calcite crystals * carbonate fossils	moderate concentration	not visible	*organic matter *iron oxides
	Little Cove	11	homogeneous fine size with larger crystals	*varied concentration of calcite crystals * carbonate fossils	moderate concentration	not visible	* organic matter * iron oxides
	Soldier Point	3	homogeneous fine size with larger crystals	* varied concentration of calcite crystals * carbonate fossils	moderate concentration	not visible	* organic matter * iron oxides
(secondary)	Blackman's Point	8	homogeneous fine size with larger crystals	* low concentration * some fossils	varying concentration low to high	not visible	* organic matter * iron oxides * rectangular voids
	Coconut Hall	7	* fine size with larger crystals * very fine size * veined rock with significant presence of length-slow and radial fibrous chalcedony and macro-quartz	* varied concentration of calcite and carbonate fossils	varying concentration low to high	not visible	* organic matter * iron oxides
Antigua *(Basal Volcanic Suite)*	Shirley Heights	3	homogeneous coarse crystal size	absent	absent	not visible	-
Antigua *(Central Plain group)*	Corbison Point	9	varied sizes from very fine to coarse	* varying by bed * carbonate fossils	varying concentration low to high	not visible	varying concentrations of mud
	Dry Hill	4	varied sizes from very fine to coarse	* varying by bed * carbonate fossils	varying concentration low to high	not visible	varying concentrations of mud
St. Kitts *(unknown geological origin)*	Great Salt Pond and Sugar Factory Pier	10	homogeneous very fine size	* low concentration * some carbonate fossils	low concentration	not visible	organic matter
Puerto Rico *(Guanajibo Formation)*	Cerrillos	4	* varied quartz sizes from very fine to coarse * veined rock with significant presence of length slow chalcedony and macro-quartz	absent	absent	not visible	iron oxides
	Pedernales	4	* homogeneous fine size * veins with length slow chalcedony and macro-quartz	absent	absent	not visible	-
Puerto Rico *(Ponce Formation)*	Las Palmas	7	* varied sizes from very fine to coarse * significant presence of length-slow and radial fibrous chalcedony and macro-quartz	absent	absent	not visible	iron oxides
Puerto Rico *(Cotui Formation)*	Villa Taina	4	* varied sizes from very fine to coarse * significant presence of length-slow and radial fibrous chalcedony and macro-quartz	absent	absent	not visible	iron oxides
Puerto Rico *(San Sebastián Formation)*	Moca	3	* varied sizes from very fine to coarse * veined rock with presence of radial fibrous and length-slow chalcedony and macro-quartz	absent	absent	not visible	varying concentrations of mud

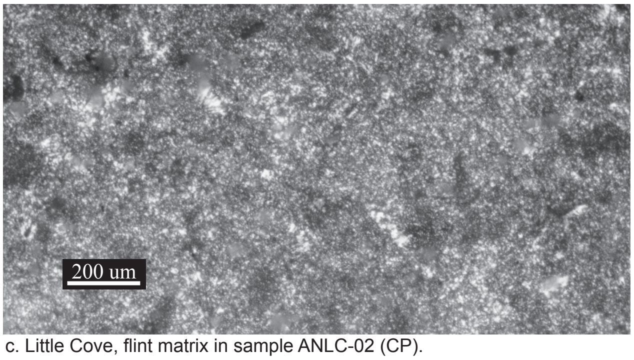
Table 2.3. Microscopic characteristics of the flint and chert by source. N denotes the number of thin-sections analysed.



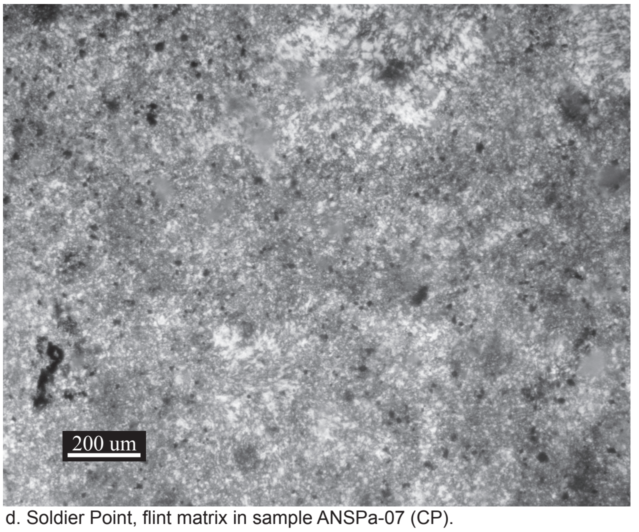
a. Long Island, flint matrix in ANLI-02 (CP).



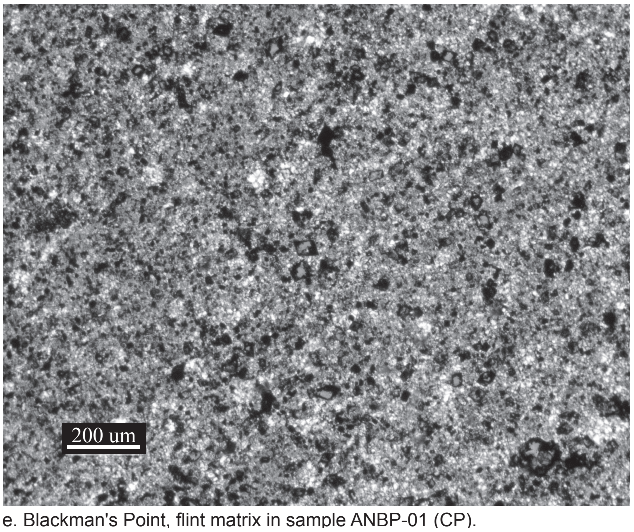
b. Long Island, flint matrix in sample ANLI-11 (CP).



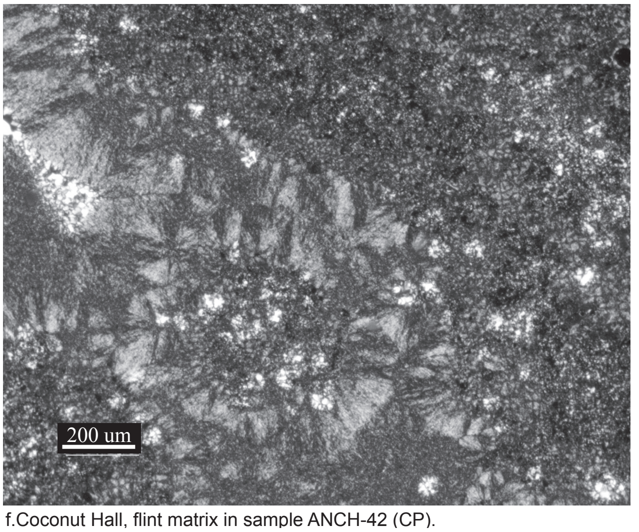
c. Little Cove, flint matrix in sample ANLC-02 (CP).



d. Soldier Point, flint matrix in sample ANSPa-07 (CP).

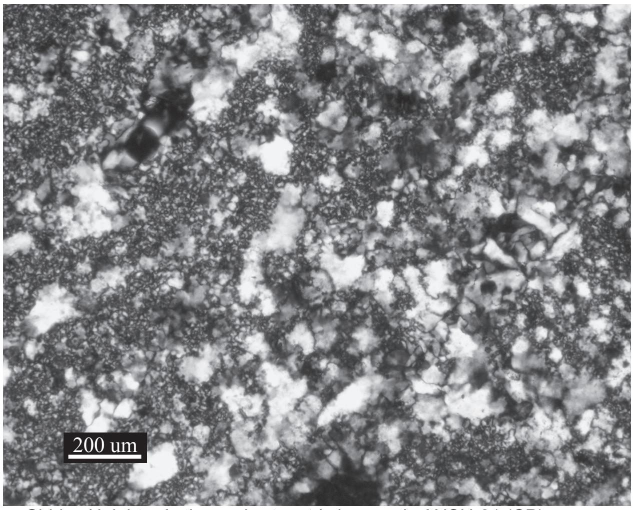


e. Blackman's Point, flint matrix in sample ANBP-01 (CP).

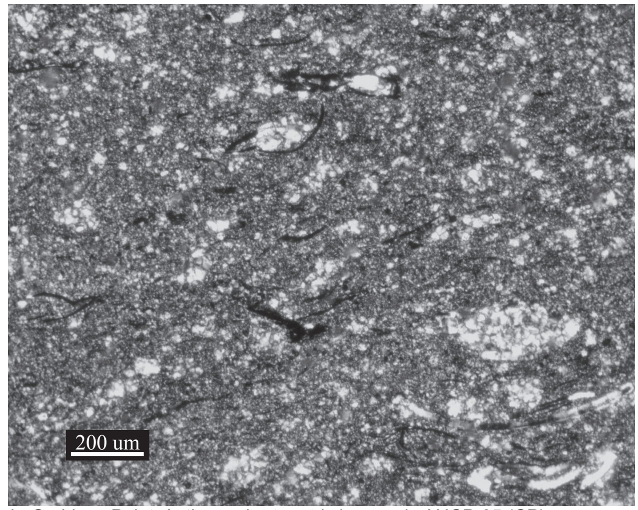


f.Coconut Hall, flint matrix in sample ANCH-42 (CP).

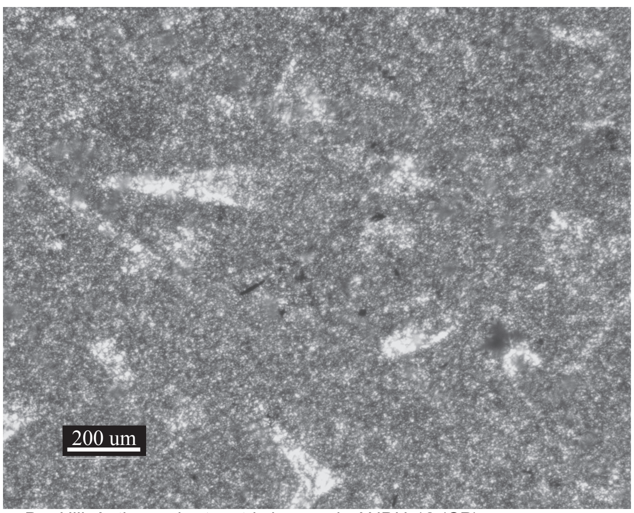
Figure 2.15. Thin-section photos of Antigua Formation flints in crossed polars (CP).



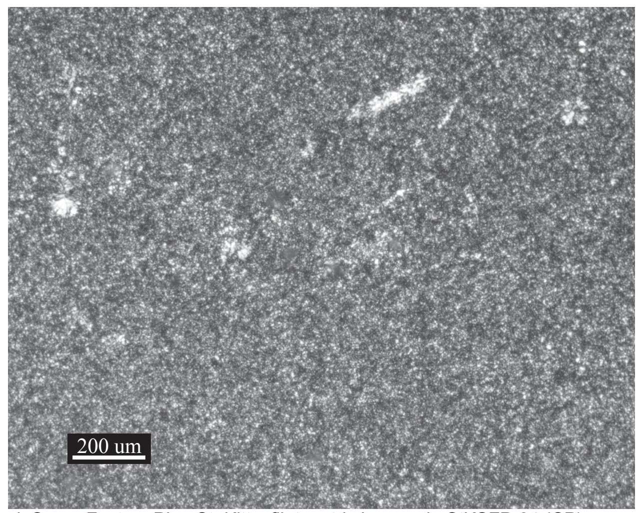
a. Shirley Heights, Antigua, chert matrix in sample ANSH-01 (CP).



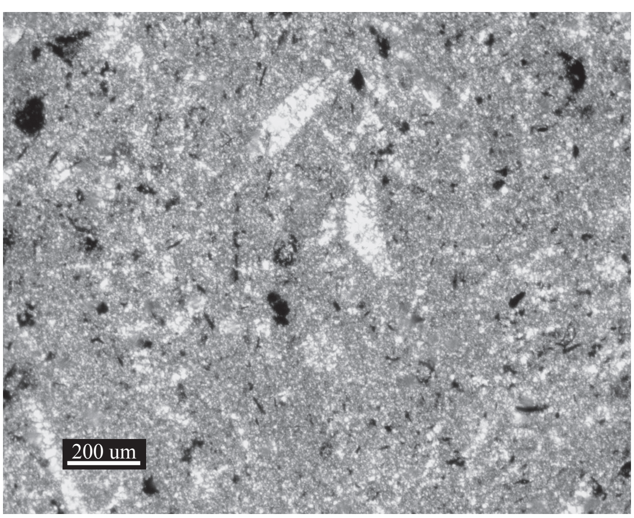
b. Corbison Point, Antigua, chert matrix in sample ANCP-05 (CP).



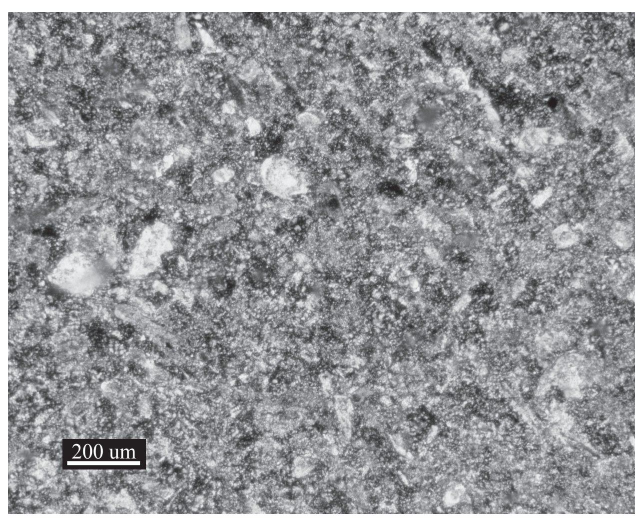
c. Dry Hill, Antigua, chert matrix in sample ANDH-12 (CP).



d. Sugar Factory Pier, St. Kitts, flint matrix in sample StKSFP-04 (CP).

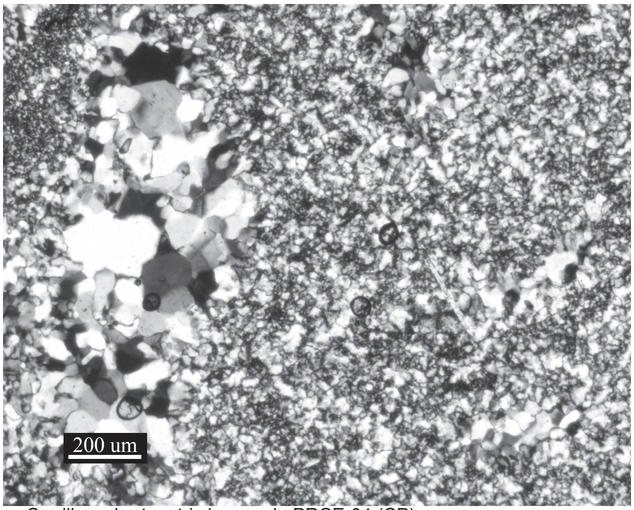


e. Sugar Factory Pier, St. Kitts, flint matrix in sample StKSFP-03 (CP).

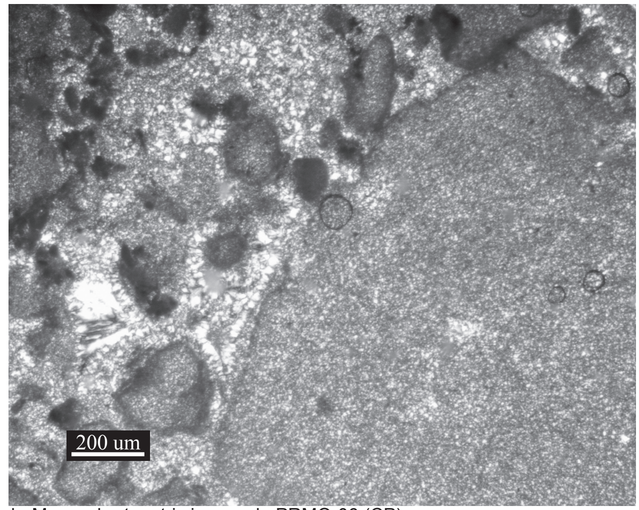


f.Great Salt Pond, carbonate rich flint matrix in sample StKGSP-02 (CP).

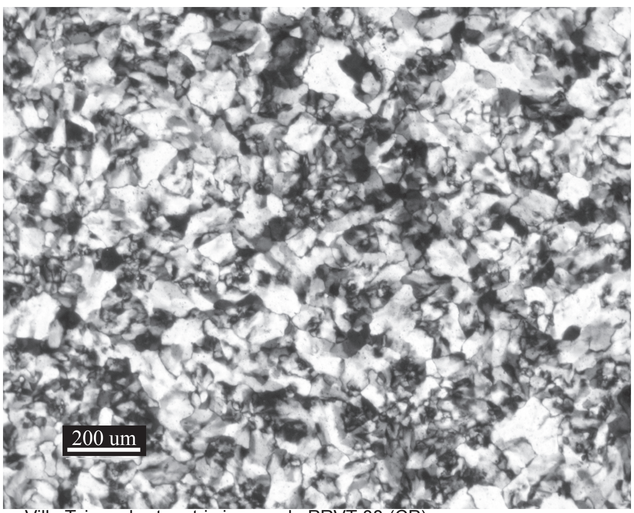
Figure 2.16. Thin-section photos of Antigua tuff cherts and St. Kitts flints in crossed polars (CP).



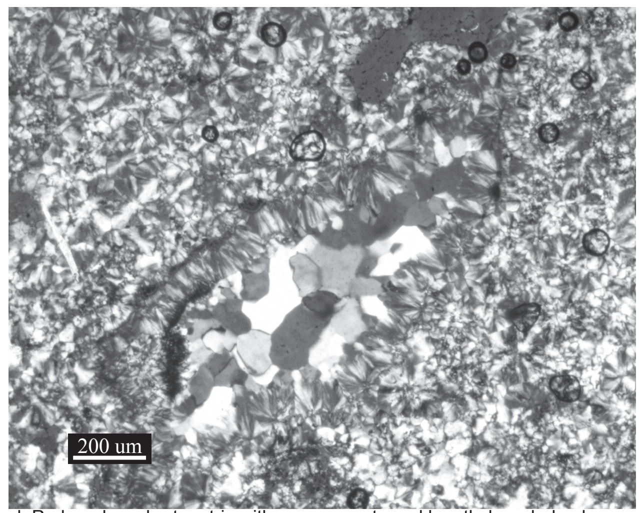
a. Cerrillos, chert matrix in sample PRCE-04 (CP).



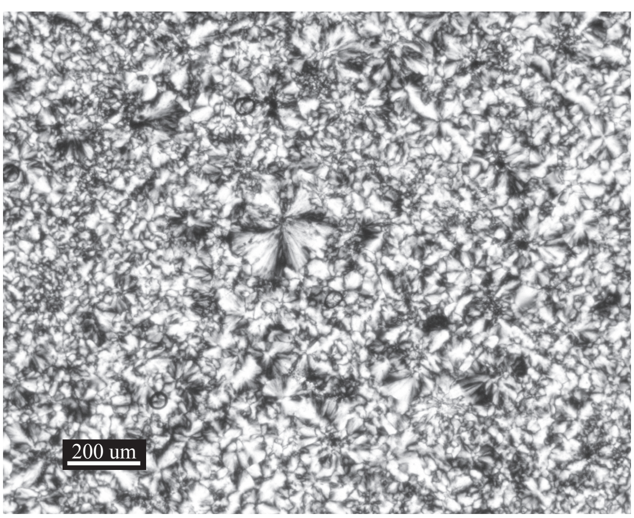
b. Moca, chert matrix in sample PRMO-06 (CP).



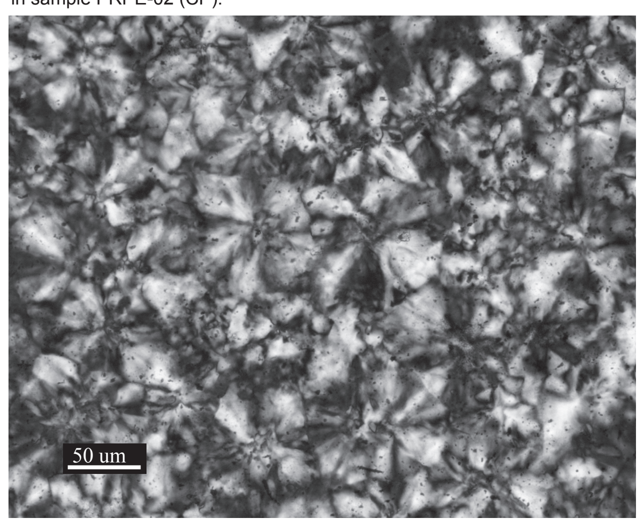
c. Villa Taina, chert matrix in sample PRVT-08 (CP).



d. Pedernales, chert matrix with macro quartz and lengthslow chalcedony in sample PRPE-02 (CP).



e. Las Palmas, chert matrix with radial chalcedony in sample PRLP-04 (CP).



f. Las Palmas, close-up of radial chalcedony in sample PRLPa-13 (CP).

Figure 2.17. Thin-section photos of Puerto Rican cherts in crossed polars (CP).

is generally darker and grain-size is finer. Furthermore, the flint displays a haze of fine calcite particles in its matrix, which makes it different from the other Antigua Formation flints. These differences may be explained by the fact that primary flint at Long Island is predominantly found in another form (around U-shaped burrow tubes; see figure 2.9) and within another limestone deposit than the Antigua flints mentioned above (see Appendix A). One primary outcrop on Long Island, however, is present in nodule form as well, and more closely resembles these other flints.

Contrary to the primary Antigua Formation flints, the same flint type from a secondary context displays much more variation. In particular, flint from Long Island, as well as material from the exclusive secondary sources of Blackman's Point and Coconut Hall, had experienced clear macroscopic change in colour, as well as grain-size as a result of weathering. Change has also been noted for the Little Cove and Soldier Point flints. However, here it has less significant implications, as the secondary flints solely exhibit lighter hues within the same colour range. Flint at Blackman's Point and Coconut Hall also has varying grain-sizes, including coarser varieties not encountered among the other Antigua Formation sources. Among the Blackman's Point flint, the influence of weathering is clearly visible under the microscope. Generally, this flint type has a very low calcite contents. Original calcite in the matrix has been lost as a result of dissolution, making the flint porous and therefore, giving it a lighter colour. At Coconut Hall, the flint matrix displays additional features not encountered among the other Antigua Formation flints. Some of the samples possess veined areas in which the quartz crystal size and type is different. This differentiation suggests multiple episodes of silification. Similar veined areas are present among some of the Puerto Rican cherts as well. Both groups also share the occurrence of a radial fibrous type of chalcedony (see Schubel & Simonson 1990 for a similar example), in which chalcedony building occurs from a centre point, in contrast to length-slow chalcedony, in which chalcedony growth is along a boundary. The presence of these features in the Coconut Hall flint is not fully understood. It is at least clear that the formation of this flint underwent a slightly different trajectory than the other Antigua Formation flints.

The tuff cherts from Antigua can be divided into two groups: (1) the cherts formed in calcareous tuff at Corbison Point and Dry Hill; and (2) the cherts formed in non-calcareous tuff at Shirley Heights. The latter type is clearly distinguishable by its light grey to almost white colour, a feature rarely found among the other chert and flint sources. Furthermore it does not contain visible inclusions, unlike the other tuff cherts, which in some cases display clear fossils. Therefore, these fossil rich tuff cherts in some way resemble the flints from Antigua. In the first place, their dark grey brown colour is much more similar to the Antigua flints. In the second place, the presence of fossils resembles the flints as well, although it has to be remarked that fossil types differ. Close intra-source comparison of the Corbison Point locality in particular shows that the different beds exposed at this rock point vary. In combination with the chemical data, four sub-varieties, each corresponding with a single bed can be distinguished. These are (A) a pure quartz chert without inclusions, (B) a bioclast rich and carbonate poor chert, (C) a bioclast rich and carbonate rich chert, and (D) a dirty bioclast poor chert, much resembling some of the Antigua Formation flints. Chert at Dry Hill is only similar to two out of these four varieties. Analogous to the Little Cove and Soldier Point flints, secondary chert at the cobble beaches of Corbison Point and Dry Hill, has turned lighter in colour.

Flint from St. Kitts clearly possesses features, that suggest its formation within limestone host-rock. First of all, many of the samples display the presence of fossils. Second of all, microscopic analysis confirmed the presence of calcite. These two features were both found among the material from the two sampled localities. The detailed analysis of this material also revealed that material from both localities is to be considered the same. Flint from both sources displays the same colour range, grain-size, and clast contents. This similarity is confirmed by the chemical data. This suggests that flint on St. Kitts originates from the same geological setting.

Compared to the Antigua cherts and flints, as well as the Puerto Rico cherts, the flint from St. Kitts is clearly distinguishable by its fine crystalline texture, as seen under the microscope. All samples exhibit a very fine homogeneous matrix, which is different from the other cherts within this research, which generally possess a broader range of grain-sizes, giving the rocks a varied appearance under the microscope.

Cherts from the different sources in Puerto Rico for their part display considerable intra-source variation, probably owing to their exclusive secondary nature in which weathering must have had a significant effect. This is in the first place clearly evidenced by the broad range of colours encountered, which generally lie in the red to reddish brown to light brown hue types.

Also, on a microscopic level variation is notable. The chert matrix differs a lot. Many samples are built up by quartz, which is larger in crystal size than most of the other sources within the study. Only Shirley Heights chert from Antigua possesses a similarly large crystal size. Many samples are veined as well, in which vein filling is different from the surrounding matrix. In most cases, macro-quartz fills these veins, surrounded by a chalcedony rim, which marks the boundary between matrix and vein filling. In some cases, veins are either completely filled with chalcedony or very fine quartz similar to the St. Kitts matrix. As in the Coconut Hall flints, these veins represent later phases of silification compared to the matrix. In addition to these types of quartz, the radial fibrous type of chalcedony, also present within the Coconut Hall flint, was identified (see above).

Comparing the different chert sources, it can be noted that despite the intra-source variation the cherts from the different localities share a number of features. These include: (a) absence of bioclasts, (b) absence of detrital litho-casts, (c) absence of calcite, and (d) a variable chert matrix, including veins or areas, which had been silicified during a later phase of silicification. Furthermore, a large portion displays the influence of iron staining and oxidation. The structural absence of bioclasts and calcite indicate that the cherts are not true flints similar to the Antigua Formation and St. Kitts ones, in which quartz has replaced original carbonate host-rock. Still the data at present are inconclusive to fully understand the formation and presence of chert at these different localities. Future research should focus on the identification of any primary deposits of chert in close vicinity to the different scatters.

2.4 Chemical characterisation

2.4.1 Introduction

In this section, I will highlight and explain some of the differences between the chert varieties that were encountered during this research. The aim here is to understand why chert localities vary. In general, it can be stated that variation among chert sources may be caused by the difference in the processes that are associated with its formation and its post-formational history. Chert formation in all its different forms is not fully understood. However, it is generally agreed that it represents a replacement of the original host-rock. Therefore, differences in composition can be a result of the variation in original sediment/host-rock, which may vary in time and space (Bush & Sieveking 1986).

The post-formational history relates to all processes that operated on the rock after its formation, and mainly can be summarised under the name "weathering". Weathering may primarily vary, depending on the type of soil and agents occurring in the soil (e.g., plants), as well on the atmospheric conditions under which and time period during which a rock has been exposed to these processes. The subject of weathering is of primary interest as many of the sources in this study are secondary in nature. In some cases, this has resulted in clearly distinct looking cherts. Others have already shown that secondary material may differ from primary material in macroscopic, microscopic, as well as chemical features (Lavin & Prothero 1992).

1) Environment of formation
    a. type of host-rock (carbonate/tuff/volcanic)
        i. time (layer/formation)
        ii. place (location within layer/formation)

2) Environment of weathering
    a. type of soil/surface (carbonate soils/tropical ferric soils/clayey soils/beach environment)
    b. atmospheric condition (climate)
        i. speed - time (period of exposure to weathering)

2.4.2 Origin of the trace-elements

Chert rocks almost exclusively consist of quartz, in micro- to crypto-crystalline form. This means that silicon (Si) and oxygen (O) atoms mainly make up the rock. They usually account for more than 95% of the total constituents agents. Other elements may occur in minor amounts, however. Usually the variation of the concentration of these trace-elements provides the basis on which sources can be distinguished. Therefore, major attention needs to be devoted to the understanding of the trace-element composition of the different cherts. Earlier work has summarised the following main fractions in which the trace-elements, used in this study, can occur (Bush & Sieveking 1986; Cowell 1981; Kars *et al*. 1990; Luedtke 1992):

1) As impurities (cations) within the quartz structure. Usually this is in very low concentrations. Major portions of Li and Cr may be attributed to this fraction, but also minor amounts of K, Al, and Na.
2) Within the remaining relics of the original host-rock, e.g., carbonate, which has not been replaced. Primary elements associated with a carbonate fraction are Ca, Mg, and Sr.
3) Within rock-forming minerals with a terrestrial or marine authigenic origin, e.g., clays, tuffs, detrital minerals. This fraction is responsible for the main portion of the trace elements such as Al, K, Ti, and Cr, but also for minor portions of Fe, Ca, Mg, Sr, and Na.
4) In iron minerals, e.g., pyrite. Fe, Mn, and S
5) Within organic material, S
6) As salts in the remaining interstitial water. This is the main origin for Na.

Apart from carbonate material, which can be present in significant amounts within flints (nodular cherts formed in limestone) (Kars *et al.* 1993), resulting in high Ca, Mg, and Sr concentrations, the main origin of most of the other trace-elements in cherts are clay-minerals or other fine (detrital) rock-minerals. These minerals may have different origins. They may be terrestrial, i.e. tuffs or the products of weathered rock, transported to the sea by rivers, or by volcanic or eolian processes. Alternatively, they may be clay minerals that have an authigenic marine origin (Weaver 1989). Usually, authigenic marine clay minerals are formed from available terrestrial minerals, which are changed in structure as a result of the difference in chemistry between fresh water and the newly encountered saline marine environment (Weaver 1989).

With regard to the terrestrial origin of the clay mineral suite, a nearby volcanic origin was probably of more influence than a distant eolian transport in case of the islands of Antigua and St. Kitts.[7] This in particular accounts for the Antigua cherts formed in tuffs. As a consequence, this means that the type of clay-minerals formed must be related to the igneous rock that became exposed to weathering.

Igneous rock in Antigua and St. Kitts are both calc-alkaline in nature. These have low K, moderate Fe and Mg, and high Al contents. The most common clay mineral formed as a weathering product is a smectite, an Al-rich silicate with small amounts of Fe and Mg (Weaver 1989). This is a frequently encountered clay mineral within igneous rock regions. The fact that Weiss (1994) reports smectitic clay deposits on Antigua confirms this hypothesis. If this smectite is transported to the sea, a change in composition will occur when it reaches the new saline environment. As a result of the change in water chemistry, the smectite will incorporate K and Mg, which are more available in marine waters, into their expanded layers (Weaver 1989). Illites and chlorites are likely to be formed then. This means that the clay mineral suite associated with the igneous origin of both islands will most likely consist of a mixture of smectite, derived illite, and derived chlorite.

In addition to these minerals, a common clay-mineral in sedimentary rocks is glauconite. It can form authigenically in marine environments where it is found in different forms, as fecal pellets from filter feeding organisms, as internal molds or casts of carbonate microfossils, and as biogenic carbonate debris. Comparing the structure and chemistry, it can be noted that glauconites are 2:1 layer clay-minerals, similar to smectites and illites. In fact, it can be considered as a Fe-rich illite or mica (Weaver 1989).

When it is formed authigenically in seawater, generally it can be said that the Al and Si may be derived from other clay-minerals, e.g., fecal pellets or detrital clays. First, Fe is incorporated, then K. As glauconite is actually a rich Fe-mica (illite), this might suggest that it formed either from available illite (see above) by only incorporating Fe, or that it may have formed from smectite by incorporating Fe and K.

From this it can be outlined that a high detrital terrestrial input will result in relative high amount of smectite. In contrast, significant marine influence on the mineral suite will produce high amounts of illite, chlorite, and glauconite. Translated to the trace-element chemistry of the cherts, this means that relatively high terrestrial input results in a high concentration of Al with respect to K, Mg and Fe, whereas a high marine derived input will either result in relatively high K, Mg, and Fe, depending on the type of mineral present.

Considering the fact that significant amounts of Mg and Fe can originate from fractions other than a clay-mineral one, respectively carbonates (Mg) and iron minerals in the form of pyrite (Fe), these two elements form poor indicators of clay-mineral presence. Therefore, major attention will be devoted to the Al-and-K-comparison.

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[7] Due to the unclear relation between the Puerto Rican cherts and their environment of formation, a discussion of the terrestrial and authigenic origin of the elements will not be included for this island.

2.4.3 Weathering

Once rock formations erode and cherts are exposed to oxidizing conditions, they become subject to weathering. Weathering will be of significant influence from the moment they are totally eroded out of their bedrock. With regard to the weathering that can alter a rock, Brownlow (1979) considers the five following principle reactions:

1) (dis)solution
2) hydrolysis
3) ion-exchange
4) oxidation
5) organic reactions

From these, dissolution is of main concern to this research, since it represents the reaction by which relatively resistant quartz is lost following the equation.

$$Si_2O + 2H_2O \rightarrow H_4SiO_4$$

This process only occurs very slowly under neutral or high pH. The dissolution rate of quartz under these conditions does not exceed 10 ppm. If the pH, however, rises above 9, the dissolution of quartz displays a very steep increase, as result of the dissociation of silicic acid.

$$H_4SiO_4 \rightarrow H^+ + H_3SiO_4^-$$

Röttlander (1975a, b, 1989) also found out that certain humic acids, containing a (1,2-dihydroxidebenzene) group, more easily dissolve quartz than would be expected on the basis of this behaviour, even under decreasing pH conditions.

Calcite, one of the important minor constituents of flint, is lost as well by dissolution. This mineral relatively easily dissolves in nature as a result of the presence of dissolved carbon dioxide in most waters. The dissolution rate increases with low pH.

$$CaCO_3 + H_2CO_3 \rightarrow 2HCO_3^- + Ca^{2+}$$

It should be noted that at low pH silica precipitates and carbonate dissolves, explaining the replacement of carbonate by silica, in particular upon exposure to carbon-dioxide rich rainwater and groundwater in contact with oxidising organic matter.

Other weathering reactions that may occur are oxidation and to a lesser extent, hydrolysis. The primary oxidation reactions mainly involve iron or manganese in flints and cherts. Pyrite, for example, is oxidized by the following reaction:

$$4FeS_2 + 15O_2 + 8H_2O \rightarrow 2Fe_2O_3 + 8SO_4^{2-} + 16H^+$$

The resulting agents are a very insoluble ferric oxide and a soluble sulphate. The ferric oxide gives the typical red-brown colour to the rock.

2.4.4 Results

Introduction

Considering the chert sources within the northern Lesser Antilles and Puerto Rico, table 2.4 summarizes the different variables for the different localities. The reader is referred to Appendix C for a complete list of all concentration values found within the different samples. Basically, two types of host-rock occur among the sources: (a) limestone and (b) tuff, with some localities being formed in a mixture of the two, e.g., Corbison Point and Dry Hill. For the sources formed within a similar host-rock, the limestone flints can be divided into the Antigua Formation flints and the St. Kitts flints, both groups of sources being formed within different geological formations. Unfortunately, the exact nature of the original carbonate host-rock of the St. Kitts remains unclear. Among the tuff cherts, localities can be found within the Basal Volcanic Suite and the Central

Island	Source Locality	Type of (original) hostrock	Type of occurrence	Weathering environment
Antigua	Long Island (LI)	Limestone	primary, secondary, tertiary	beach and soil
	Little Cove (LC)	Limestone	primary, secondary	beach
	Soldier Point (SP)	Limestone	primary, secondary	beach
	Blackman’s Point (BP)	Limestone	secondary, tertiary	beach and soil
	Coconut Hall (CH)	Limestone	secondary, tertiary	soil
	Shirley Heights (SH)	Tuff	primary, secondary	soil
	Corbison Point (CP)	Carboneous Tuff	primary, secondary	beach
	Dry Hill (DH)	Carboneous Tuff	primary, secondary	beach
St. Kitts	Great Salt Pond (GSP)	Limestone	secondary	beach and soil?
	Sugar Factory Pier (SFP)	Limestone	secondary	beach
Puerto Rico	Cerrillos (CE)	Limestone?	secondary, tertiary	soil
	Pedernales (PE)	Limestone?	secondary	soil
	Las Palmas (LP)	Limestone?	secondary, tertiary	soil
	Villa Taina (VT)	Limestone?	secondary	soil
	Moca (MO)	Conglomerrate?	secondary, tertiary	soil

Table 2.4. Weathering environment at 15 different Caribbean chert and flint sources.

Plain Group on Antigua. Within the latter geological formation, tuffs vary in their carbonate contents. Uncertainties relating to the original host-rock exist only for the Puerto Rican cherts.

At a number of the localities in this study, primary deposits co-occurred alongside secondary ones. They will be called primary sources hereafter. Only the already mentioned Puerto Rico localities, the St. Kitts ones as well as the Coconut Hall and Blackman’s Point scatters are completely secondary in nature. That is, at these localities secondary material is the only material readily available. They will be referred to as secondary sources. This means that at all localities rocks have been exposed to weathering. Only the “primary” sources provide the opportunity to compare relatively little weathered primary material[8] with more weathered secondary material.

In agreement with what would be expected, variation among cherts is smallest if they originate from a similar host-rock, within a similar geological formation (tables 2.5-9; figures 2.18-20). Variation between different host-rock cherts is more evident. The results also show that weathering may have a very significant effect on the original trace-element composition, severely altering the existing values and as a consequence, increasing intra-source variability, but also inter-source variability in some cases. This is particularly noticed for cherts that have exposed to weathering for a considerable period.

Antigua Formation flints

The Antigua Formation flints, in particular, provide good opportunities to study the variability among localities originating from a similar geological formation, as well as the effects weathering has on the flints. Primary rock samples originating from different localities can be compared. Furthermore, for some localities primary samples can be compared with secondary

[8] Primary material may have undergone some weathering in the form of oxidation. However, this will have changed the chemical composition of the rock only very slightly.

Sources	N	Al			K			Na			Ti		
		mean	sd	RSD	mean	sd	RSD	mean	sd	RSD	mean	sd	RSD
Long Island	21	1590.26	309.16	19.44	494.38	83.91	16.97	924.45	193.47	20.93	66.74	13.58	20.34
Little Cove	13	1117.03	282.40	25.28	329.72	80.49	24.41	768.01	265.65	34.59	35.17	10.33	29.38
Soldier Point	10	876.76	167.66	19.12	289.94	66.17	22.82	604.20	147.73	24.45	33.40	9.91	29.68
Blackman's Point	12	519.19	219.43	42.26	127.80	80.33	62.86	400.13	328.06	81.99	17.19	9.60	55.85
Coconut Hall	11	335.82	162.67	48.44	106.59	42.38	39.76	155.33	60.74	39.10	27.99	49.53	176.97
Corbison Point	7	880.42	790.06	89.74	196.07	158.77	80.98	489.74	405.90	82.88	59.03	41.63	70.52
Dry Hill	13	309.54	122.32	39.52	84.63	46.61	55.07	491.16	184.68	37.60	13.01	7.20	55.33
Shirley Heights	9	1716.62	1301.74	75.83	336.70	191.86	56.98	329.30	161.83	49.14	75.41	68.33	90.61
Cerillo	13	287.10	147.98	51.54	58.30	26.41	45.29	61.07	32.58	53.35	9.29	5.74	61.83
Las Palmas	8	141.13	100.37	71.12	79.74	41.32	51.82	113.21	63.79	56.34	5.83	8.98	154.17
Pedernales	6	214.62	72.69	33.87	111.79	71.35	63.82	103.98	67.38	64.80	10.70	7.87	73.56
Villa Taina	11	284.64	114.44	40.20	48.20	20.64	42.83	99.97	23.62	23.63	4.51	2.63	58.27
Moca	8	281.20	240.16	85.40	113.50	78.30	68.98	165.93	97.25	58.61	14.12	17.19	121.76
St. Kitts	15	471.04	208.91	44.35	272.06	86.96	31.96	574.71	180.21	31.36	16.92	8.95	52.92

Table 2.5. Average values (mg/kg (ppm)), standard deviations (mg/kg (ppm)), and relative standard deviations (RSD) of trace-element concentrations within Caribbean flints and cherts by source.

Sources	N	Li			Cr			Fe			Mn		
		mean	sd	RSD	mean	sd	RSD	mean	sd	RSD	mean	sd	RSD
Long Island	21	13.88	2.67	19.20	6.72	1.53	22.80	459.60	190.10	41.36	2.76	2.51	90.96
Little Cove	13	13.68	4.21	30.79	4.47	1.09	24.34	204.38	110.46	54.05	0.69	0.28	40.77
Soldier Point	10	11.29	1.63	14.45	3.48	0.80	22.99	234.22	69.83	29.81	1.32	0.64	48.26
Blackman's Point	12	10.46	6.02	57.54	4.57	1.13	24.66	1126.81	1278.08	113.43	6.12	8.59	140.28
Coconut Hall	11	3.49	3.18	91.16	4.05	1.85	45.79	788.75	617.49	78.29	41.44	123.99	299.20
Corbison Point	7	14.84	11.76	79.28	1.40	0.43	31.02	401.97	873.94	217.41	3.55	3.61	101.67
Dry Hill	13	4.96	4.06	81.92	-	-	-	647.77	457.07	70.56	25.82	54.07	209.44
Shirley Heights	9	6.76	4.40	65.11	5.42	3.34	61.53	1370.41	2159.52	157.58	166.08	295.16	177.73
Cerillo	13	6.40	6.39	99.87	47.27	51.48	108.92	1498.80	1519.24	101.36	7.95	4.92	61.93
Las Palmas	8	1.67	1.03	61.80	19.73	21.70	109.97	3062.67	3462.91	113.07	32.04	52.85	164.96
Pedernales	6	2.55	1.21	47.53	7.55	7.64	101.11	1825.92	1048.16	57.40	16.61	10.27	61.85
Villa Taina	11	4.68	2.89	61.70	22.29	10.10	45.32	730.94	1200.80	164.28	6.67	11.78	176.68
Moca	8	8.14	3.23	39.69	14.40	16.30	113.21	226.91	123.30	54.34	2.25	1.77	78.68
St. Kitts	15	3.73	3.47	93.05	14.01	40.57	289.54	309.52	322.99	104.35	3.99	5.43	136.16

Table 2.6. Average values (mg/kg (ppm)), standard deviations (mg/kg (ppm)), and relative standard deviations (RSD) of trace-element concentrations within Caribbean flints and cherts by source.

Sources	N	S			Al/K			Al/Fe			Al/Li		
		mean	sd	RSD	mean	sd	RSD	mean	sd	RSD	mean	sd	RSD
Long Island	21	356.30	238.88	67.05	3.21	0.26	8.16	4.16	2.66	64.07	114.91	11.86	10.32
Little Cove	13	50.18	12.34	24.60	3.39	0.18	5.25	8.29	7.22	87.14	84.13	12.85	15.28
Soldier Point	10	89.33	61.52	68.87	3.08	0.42	13.68	3.94	1.06	26.98	78.64	16.51	21.00
Blackman's Point	12	63.26	76.63	121.15	4.60	1.52	32.97	0.84	0.68	81.49	121.38	25.14	20.72
Coconut Hall	11	306.25	464.12	151.55	3.26	1.03	31.62	0.73	0.67	92.05	74.93	61.56	82.16
Corbison Point	7	-	-	-	4.50	1.27	28.13	18.19	8.18	44.99	146.93	79.84	54.34
Dry Hill	13	135.15	167.33	123.81	4.50	1.58	35.14	3.30	2.84	86.15	233.85	50.77	21.71
Shirley Heights	9	155.61	302.04	194.10	4.66	3.87	83.00	1.89	2.33	122.83	67.68	15.95	23.57
Cerillo	13	37.44	14.48	38.68	5.26	3.04	57.77	0.43	0.52	120.76	120.46	112.42	93.33
Las Palmas	8	23.64	9.28	39.25	7.02	4.07	58.07	0.34	0.31	90.67	69.09	45.32	65.59
Pedernales	6	-	-	-	2.77	0.68	24.75	0.26	0.31	120.59	94.62	92.10	97.34
Villa Taina	11	43.88	11.91	27.15	1.85	0.86	46.49	0.40	0.35	88.12	59.85	6.69	11.18
Moca	8	16.36	-	-	2.36	1.31	55.41	1.15	0.49	42.91	146.94	159.04	108.23
St. Kitts	15	131.91	149.30	113.18	1.73	0.49	28.09	2.77	2.05	74.05	94.06	46.34	49.27

Table 2.7. Average values (mg/kg (ppm)), standard deviations (mg/kg (ppm)), and relative standard deviations (RSD) of trace-element concentrations within Caribbean flints and cherts by source.

Sources	N	Ca			Mg			Ba			Sr		
		mean	sd	RSD	mean	sd	RSD	mean	sd	RSD	mean	sd	RSD
Long Island	21	1805.73	2203.06	122.00	457.26	714.58	156.27	41.20	66.88	162.36	16.58	10.36	62.48
Little Cove	13	2551.44	2994.93	117.38	107.29	35.47	33.06	35.24	43.56	123.61	10.31	4.63	44.94
Soldier Point	10	2749.95	3660.49	133.11	73.99	19.18	25.92	3.01	1.57	52.28	12.29	10.33	84.00
Blackman's Point	12	266.66	137.19	51.45	71.78	72.21	100.59	10.57	14.36	135.83	9.95	9.50	95.44
Coconut Hall	11	336.99	391.76	116.25	129.83	403.18	310.54	8.82	8.74	99.03	19.33	49.85	257.90
Corbison Point	7	219.76	127.63	58.08	32.75	17.05	52.07	59.24	63.56	107.29	28.74	26.72	92.97
Dry Hill	13	8007.52	12356.1	154.31	200.97	207.19	103.10	33.07	38.93	117.74	30.63	24.64	80.45
Shirley Heights	9	12816.0	16008.8	124.91	532.17	473.71	89.01	3.96	4.16	105.16	26.12	26.09	99.90
Cerillo	13	49.71	89.70	180.44	352.95	244.98	69.41	8.06	10.61	131.53	1.82	1.62	89.30
Las Palmas	8	228.73	235.68	103.04	199.93	181.49	90.77	25.06	24.46	97.63	2.29	0.95	41.51
Pedernales	6	126.27	104.41	82.68	186.13	244.03	131.11	12.51	11.67	93.30	1.77	0.86	48.91
Villa Taina	11	193.46	235.49	121.72	163.53	184.22	112.65	19.28	39.74	206.17	2.24	2.01	89.70
Moca	8	144.67	148.31	102.52	86.56	88.91	102.72	3.34	3.41	102.04	1.32	0.42	32.14
St. Kitts	15	3636.95	9892.82	272.01	177.60	217.61	122.53	4.72	5.38	113.96	10.30	17.66	171.44

Table 2.8. Average values (mg/kg (ppm)), standard deviations (mg/kg (ppm)), and relative standard deviations (RSD) of trace-element concentrations within Caribbean flints and cherts by source.

Sources	N	Ca/Mg		
		mean	sd	RSD
Long Island	21	5.82	4.38	75.28
Little Cove	13	20.35	15.01	73.75
Soldier Point	10	32.26	30.75	95.32
Blackman's Point	12	6.52	5.28	81.00
Coconut Hall	11	22.87	17.46	76.35
Corbison Point	7	7.37	3.56	48.26
Dry Hill	13	21.67	21.01	96.96
Shirley Heights	9	19.17	16.17	84.34
Cerillo	13	0.17	0.22	128.75
Las Palmas	8	1.35	0.68	50.43
Pedernales	6	1.64	1.24	75.38
Villa Taina	11	1.48	0.67	45.34
Moca	8	1.80	0.49	27.24
St. Kitts	15	9.76	17.12	175.40

Table 2.9. Average values (mg/kg (ppm)), standard deviations (mg/kg (ppm)), and relative standard deviations (RSD) of Ca/Mg concentration ratio within Caribbean flints and cherts by source.

ones, and the heavily weathered samples from Blackman's Point provide an opportunity to study the effects of prolonged alteration.

Not considering the secondary sources for the moment, flint from the Antigua Formation is similar in microscopic and geo-chemical composition. The primary sources possess a similar texture of heterogeneously sized microcrystalline quartz crystals, with the presence of varying amounts of calcite, carbonate fossils as well as silicified ones. Furthermore, matrices exhibit a "dirty" appearance with small dark inclusions. Similarity is also attested for the geo-chemical data (tables 2.5-9). Most striking resemblances are: (1) relatively constant values of clay-related elements, such as Al, K, Ti, and Fe, (2) very constant Al/K ratios (suggesting the origin from a similar suite of minerals) (figure 2.21), (3) varying Ca and Mg values, including very high concentrated samples, and (4) relatively high Li values.

This similarity suggests that despite geographical differences (different localities on the island) the environment of formation was relatively similar, in which notably the terrestrial and authigenic mineral inputs were the same. Notwithstanding these similarities, occasional differences are noted as well. These primarily are highlighted when the Long Island flint source is compared to the other localities. Within the Long Island flint, the clay-mineral related group of elements (Al, K, Ti, Cr), as well as the pyrite elements (Fe, S) is significantly higher than within the other Antigua flints. Apparently, the concentration of non-carbonate impurities within the host-rock is higher at Long Island as compared to the other sources. The type of impurities, however, is the same as similarity in the Al/K, but also shown by Al/Ti, and Al/Cr ratios between the localities.

Comparing these data to northwestern European flints, which were formed in a similar environment, the clay-derived elements have on average a higher concentration within the Antigua flints. This may be related to the smaller size of the carbonate platform on Antigua when compared to that for northwestern Europe, making the terrestrial influx more predominant. Bush and Sieveking (1986, 134) noted that some of the European sources with relatively high concentrations probably were situated along the margin of the carbonate platform.

Closely studying the Al/K ratios of the Antigua flints, it is noted that they vary from 2.67 to 4.23, with the majority of the values falling in the 3.0 to 3.5 range (see Appendix C). From the above introduction it became clear that the most likely clay minerals that occurred within shallow marine waters, below which the mudstone carbonate material was deposited, include smectite, illite, chlorite and glauconite. The Al/K ratio of 3.0 to 3.5 is found in neither of the minerals individually, a mixture, however, can produce such values (table 2.10). Such a mixture contains relatively more illite and smectite compared to chlorite, or glauconite, considering the low Fe-values of the former two. As the Fe in the flints is significantly less concentrated than the Al, glauconite may have been rare, especially if we take into account that part of the Fe in the flint has originated from pyrite. A similar argument can be suggested for chlorite. Probably most of the Mg originated from the

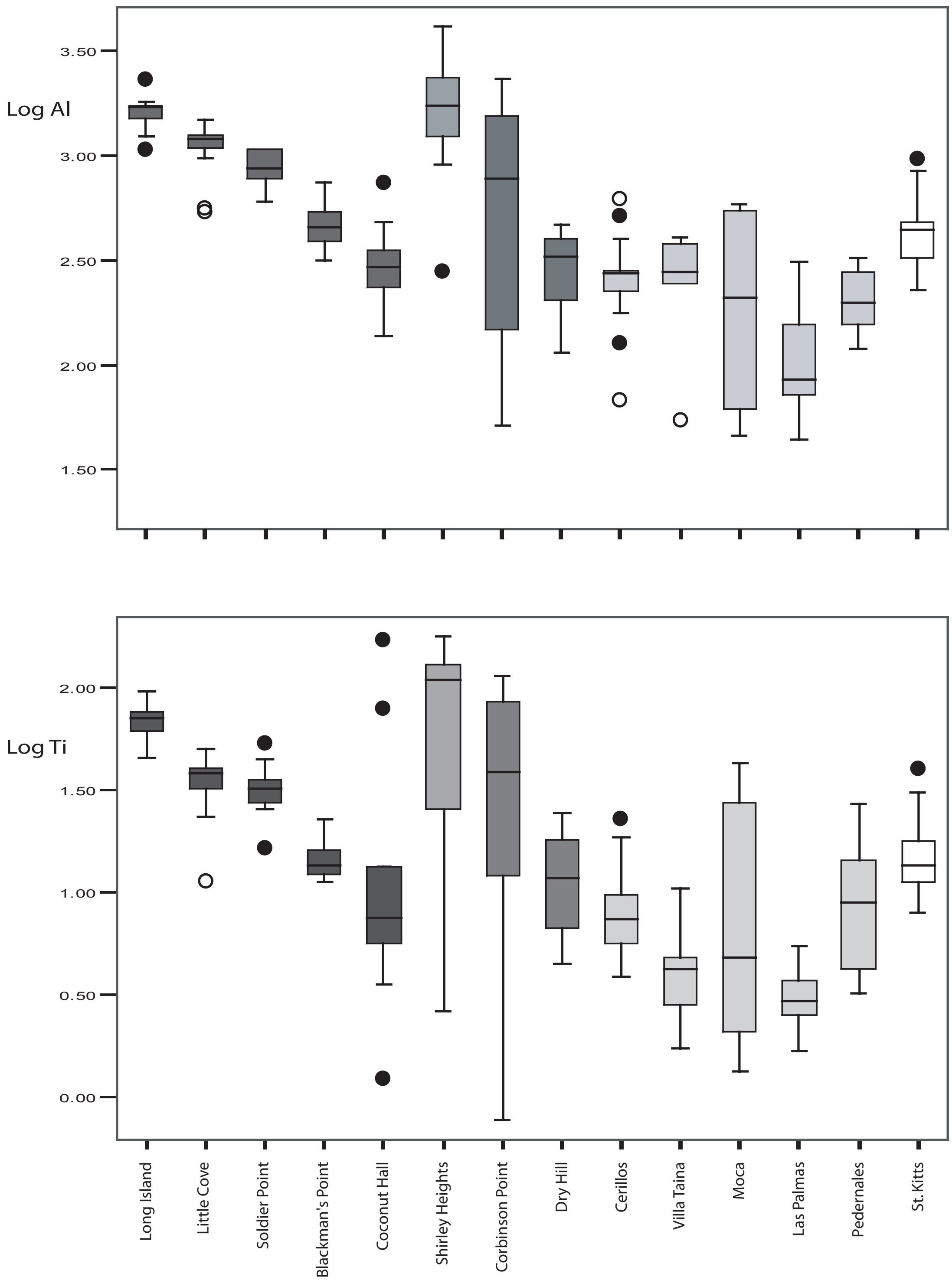


Figure 2.18. Boxplot graphs showing the log-values of Al and Ti concentrations by source grouped according to geology. Solid circles are outliers, open circles are extremes.

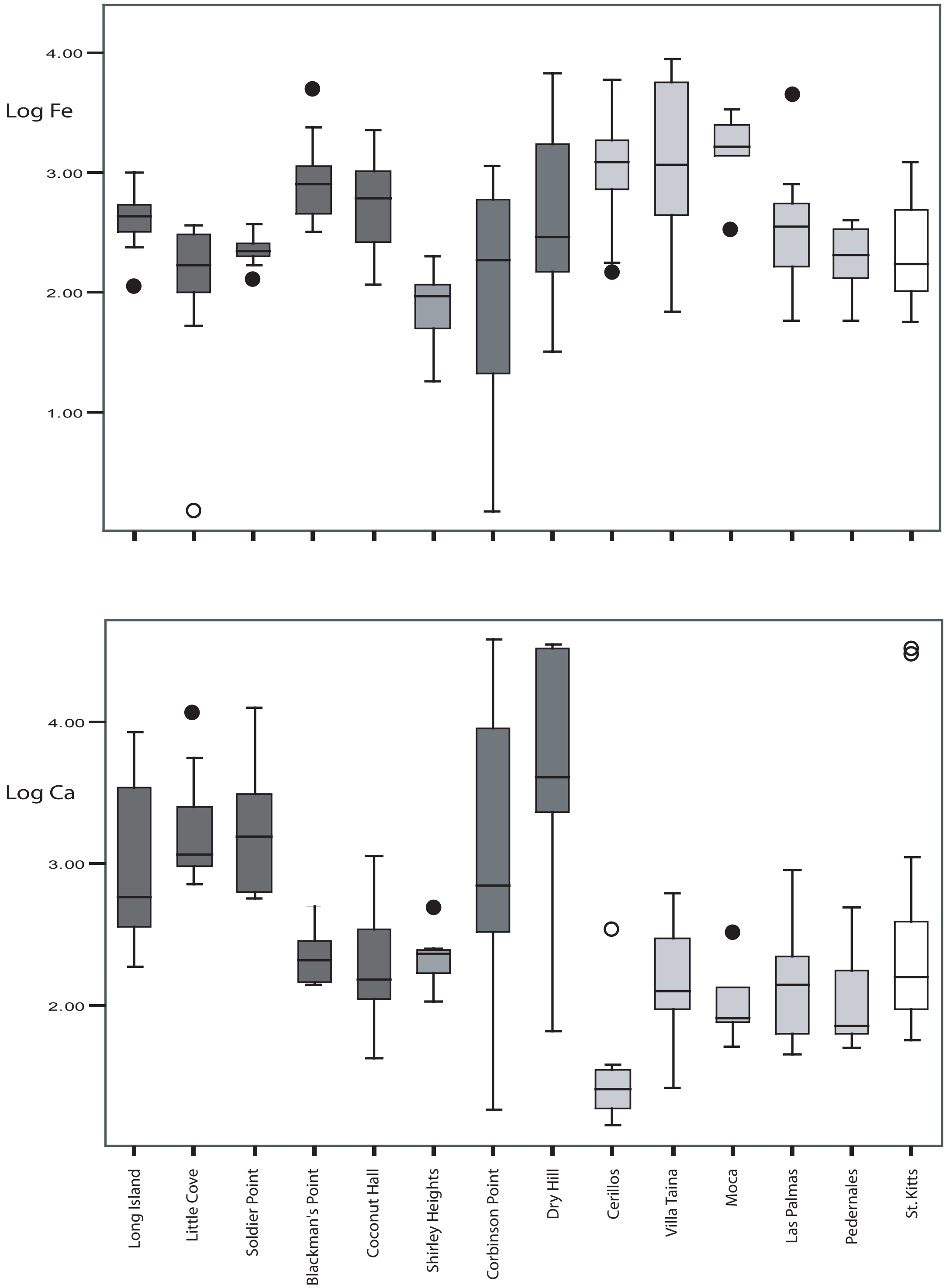


Figure 2.19. Boxplot graphs showing the log-values of Fe and Ca concentrations by source grouped according to geology. Solid circles are outliers, open circles are extremes.

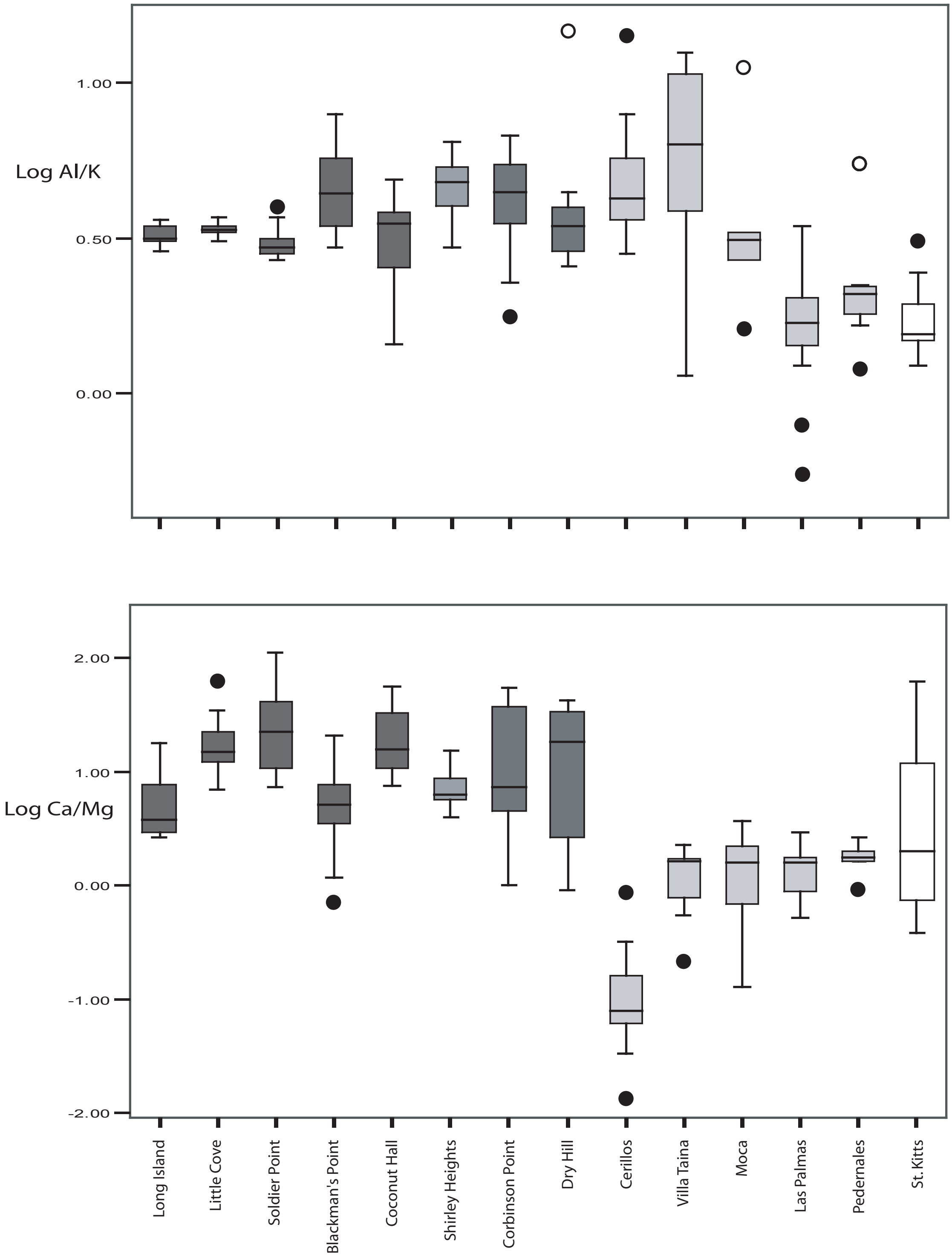


Figure 2.20. Boxplot graphs showing the log-values of Al/K and Ca/Mg concentration ratios by source grouped according to geology. Solid circles are outliers, open circles are extremes.

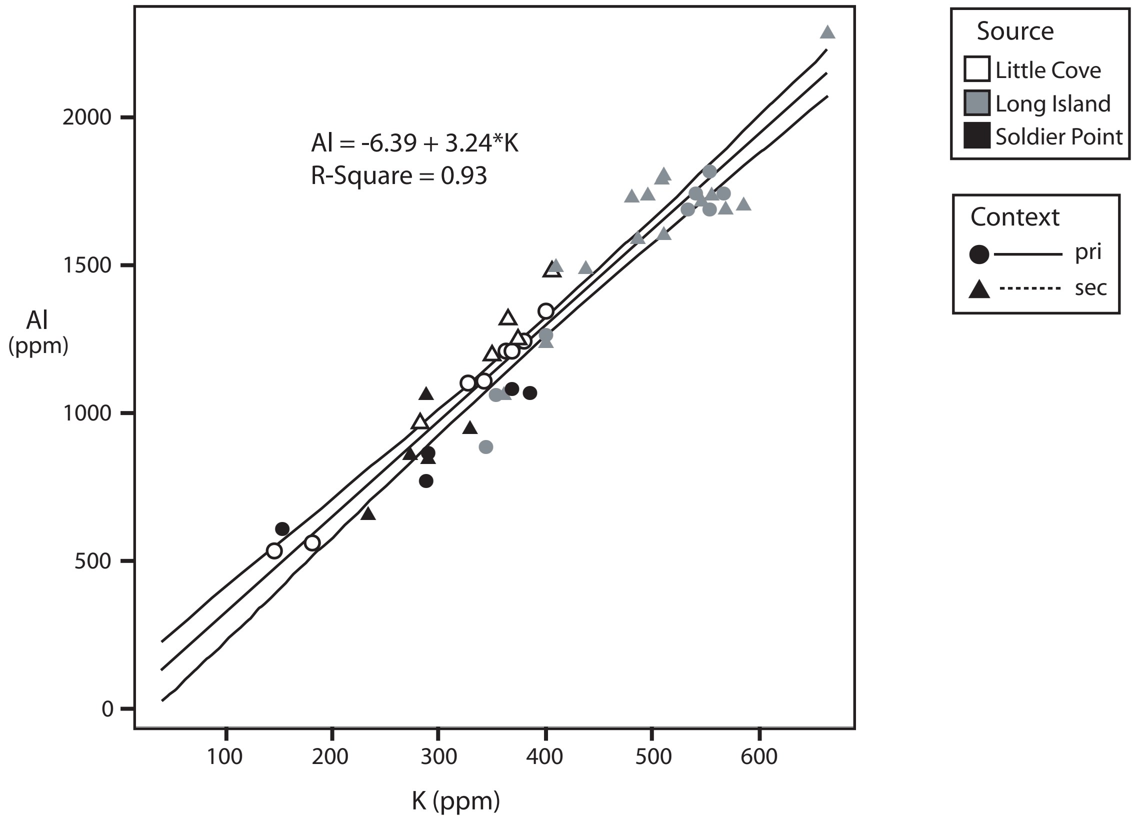


Figure 2.21. Antigua flints from primary sources. Linear regression of Al by K with 95% mean prediction interval. “Pri” stands for primary flint samples and “sec” for secondary flint samples.

carbonate grains that are still present in the flint. This suggests that a detrital smectite influx, which is for a great part changed into illite, and to a lesser extent chlorite, prevailed.

Given this resemblance in trace-element composition, additional support is provided for the fact that the flint bearing limestone layer on Antigua may have been deposited during a single event, if the points on its restricted occurrence and its similar stratigraphical position within the Antigua Formation, made earlier, are also considered. This chemical similarity, however, has negative consequences for source discrimination, in particular the Soldier Point and Little Cove flints significantly overlap in concentration values. Luckily, overlap with the Long Island material is considerably less.

Both the Long Island, Soldier Point and Little Cove sources provide data with which the influences of flint weathering can be studied. Basically, two weathering environments occur: (1) a coastal one in which sea-water is the primary agent; and (2) an inland location in which rain water and soil chemistry play the decisive role. In the former location, simple dissolution of rock material has been the primary mechanism by which the rock changes, whereas within the latter one dissolution and chemical interaction with the surrounding soil may be of significance.

The analysis of both primary and secondary samples from the Soldier Point and Little Cove localities shows that in these cases of beach weathering the trace-element composition only slightly changed. For most elements there is no significant difference between primary and secondary samples, although values of primary samples may in some cases be higher on average. Closer study of the values shows, however, that at Little Cove Na significantly, (but minimally) decreased as compared to Al and K, as is clear from higher Al/Na and K/Na ratios in the secondary flints (table 2.11). This decrease of Na must be ascribed to loss of interstitial sea-water, which stayed trapped in the flint during its formation. This decrease in Na with respect to Al and K is not present in the Soldier Point-flints, where the opposite is the case.

The analysis of secondary material from the inland soils at Long Island provides other results. Already suggested by

individual clay minerals and mixtures	reference and ratio	Al/K	Al/Fe	Al/Na
smectite 1	(Weaver 1989. p. 52.1)	83.84	10.21	86.0
smectite 2	(Weaver 1989, p. 52.6)	41.40	10.61	36.8
illite 1	(Weaver 1989, p. 43.5)	2.01	20.34	378.6
Illite 2	(Weaver 1989, p. 43.2)	2.46	17.63	47.0
chlorite 1	(Weaver 1989, p. 75.2)	-	4.71	-
chlorite 2	(Weaver 1989, p. 75.2)	-	4.71	-
glauconite 1	(Weaver 1989, p. 91.2)	1.02	0.60	40.6
glauconite 2	(st692.7)	1.52	1.53	27.7
smectite1+illite1+chlorite1+glauconite1	ratio (25/25/25/25)	2.88	2.59	131.19
smectite1+illite1+chlorite1+glauconite1	ratio (80/6.7/6.7/6.7)	8.75	5.38	96.11
smectite1+illite1+chlorite1+glauconite1	ratio (40/20/20/20)	3.46	2.97	120.31
smectite1+illite1+chlorite1+glauconite1	ratio (40/30/20/10)	3.68	4.82	155.03
smectite1+illite1+chlorite1+glauconite1	ratio (30/40/20/10)	2.43	4.46	264.52
smectite1+illite1+chlorite1	ratio (20/60/20)	2.90	11.88	293.98
smectite1+illite1+chlorite1	ratio (40/40/20)	3.91	10.51	207.12
smectite1+illite1+chlorite1	ratio (30/50/20)	3.31	11.18	245.12
smectite2+illite2+chlorite2+glauconite2	ratio (40/20/20/20)	3.97	4.96	45.60
smectite2+illite2+chlorite2+glauconite2	ratio (30/30/20/20)	3.43	5.30	46.65
smectite2+illite2+chlorite2+glauconite2	ratio (20/40/20/20)	3.06	5.64	47.61

Table 2.10. Trace element ratios in clays. Ratios from single clays are from Weaver (1989). The ratios of the mixtures are artificial and based on the single clay data with weighing factors between brackets.

the colour change among a significant part of the secondary material, where the dark greyish brown has turned into yellowish brown, chemical alteration is more significant within these inland flints than among beach-flints from the other localities.[9] Notable changes are a significant decrease of Ca, Mg, and S, and a local increase of Fe, Ba, and Sr (table 2.11). Close examination of Fe, which usually is affected as a result of oxidation, reveals that the Fe-concentration values in secondary flints are not lower on average. Variation, however, between samples has increased, as is suggested by higher RSD (relative standard deviation) values, 30.6 for primary flints and 46.7 for secondary ones. This suggests that the Fe-concentration is affected by weathering but that weathering does not necessarily work in one direction and merely redistributes the Fe within the flint concretions. Preliminary analysis of individual specimens using Laser Ablation Inductively Coupled Mass Spectroscopy (LA-ICP-MS), during which certain isolated areas can be sampled, indicates that highly concentrated Fe-bands are present in the outer part of the rock, which displays also a browner colour (figure 2.22). These bands represent Fe-oxidation borders, and may have formed as a result of Fe-transport from the inner part of the nodules. Concurrent with dissolution and transport of Fe to the outer parts, S from the pyrite is lost as well

From the Long Island samples it is also clear that Ca and associated Mg are lost in secondary flints as a result of carbonate dissolution, which was also attested among the different thin-sections. This loss is not always evident from the chemical data, as the amount of carbonate can vary a lot in limestone flints. A comparison of the primary sample LI-53, with other primary Long Island samples clearly demonstrates this variation (see table C.1 in Appendix C).

These results show that weathering only affects trace-element composition to a minor extent in case of beach weathering, whereas the soils at Long Island had a more significant effect. Most influence can be noticed in the Na, and carbonate related element (Ca, Mg) concentrations, which on average decrease. The clay and quartz related elements, such as Al, K, Li, Cr, and Ti remain relatively constant.

[9] A systematic comparison between secondary beach flints and inland flints from Long Island has not been performed, as significant erosion of the coast-line during the past eroded a lot of inland buried flint material on the beach. This hampered a sound designation of weathering environment as both flint groups became mixed on the beach.

source	Al	K	Na	Ti	Li	Cr	Fe	Ca	Al/K	Al/Na	K/Na	Al/Fe	Al/Li	Al/Ti	Al/Cr
Long Island															
primary	1484	481	1029	58.1	12.7	5.80	482	3303	3.06	1.45	0.47	3.23	115.4	25.52	254
secondary	1647	502	868	71.3	14.5	7.21	447	1007	3.29	1.94	0.60	4.65	114.6	23.15	234
Little Cove															
primary	1037	314	822	35.9	13.1	4.51	235	3121	3.32	1.33	0.40	5.98	81.4	30.35	231
secondary	1246	355	682	34.1	14.7	4.40	162	1640	3.50	1.88	0.54	11.52	88.5	37.15	337
Soldier Point															
primary	875	297	528	32.1	11.2	3.34	227	3570	3.06	1.72	0.59	3.97	79.8	28.29	268
secondary	878	283	680	34.6	11.4	3.62	241	1930	3.10	1.30	0.42	3.91	77.5	26.60	262

Table 2.11. Antigua Formation flints. Average values of trace-element concentrations (in mg/kg (ppm)) and their ratios within flints from a primary context compared to flints from a secondary context by source.

Considering the presence of primary material in clear association and near vicinity to secondary material at these sources, it can be argued that the erosion processes are still occurring and that secondary material has not been exposed to weathering for long periods on average. This may be in contrast to the other two localities within the Antigua Formation, Blackman's Point and Coconut Hall. Here the presence of primary material cannot be identified. In addition, flint material generally possesses lighter colours and in case of Blackman's Point, grain-size is coarser, possibly due to re-crystallisation. These are all features, that suggest that the rock material had been exposed to a longer period of weathering, or more severe weathering processes.[10]

In particular, comparison between the Blackman's Point flint on one hand and the Long Island, Little Cove, and Soldier Point on the other, is most instructive. Blackman's Point flint resembles the other Antigua Formation flints in many respects. Close similarity in microscopic texture suggests a similar history of formation. Only its prolonged exposure to weathering gives the flint certain different characteristics.

During the microscopic analysis, it became soon clear that most of the Blackman's Point flint samples are poor in calcite. One sample (BP-1) exhibits clear rectangular voids, 0.05 mm in length, similar in shape and size to most of the calcite minerals present in the Long Island flint samples (see figure 2.22). Close comparison of different thin-sections from Long Island and Blackman's Point reveals a continuous sequence of calcite rich non-weathered primary Long Island samples, to samples exhibiting very small voids, and finally to Blackman's Point samples with clear rectangular voids in which calcite was completely weathered out. The smaller voids are places where iron oxides were precipitated, indicated by red-brown to dark brown fillings. It should be noted that, similar to most of the secondary Long Island material, the Blackman's Point flint had been buried in soils for prolonged periods. Only along the coast-line, where the sea is gradually gaining on the land, is flint exposed.

This more significant weathering at Blackman's Point resulted in an overall decrease in trace-element concentration values for almost all analysed elements, compared to the primary flints from the other localities (see tables 2.5-9, 11). Exceptions include Fe and Mn, which generally have higher values, as well as Li, and Cr, which are less affected by the weathering. From this the following weathering sequence for all the Antigua Formation flints can be postulated.

In the first instance some Na, trapped as interstitial water, is lost. This is accompanied by the dissolution of calcite in the rock, indicated by a decrease of Ca and Mg. Slowly, the flint becomes more porous due to calcite dissolution and quartz may be more easily dissolved as a result of a higher specific surface. Porosity of the rock also induces iron and manganese oxidation. Depending on the water transport in the flint, Fe (and Mn) may be precipitated in bands in the outer parts of the rock (see Cackler *et al*. (1999a) for an example in which Mn-rich bands were formed in weathered chert). Slowly, clay minerals and other terrestrial minerals trapped in the quartz and calcite, are dissolved, resulting in lower Al, K, and Ti concentrations. K and Ti decrease relatively more in concentration than Al, as they are more reactive (Brownlow 1979), resulting in higher Al/K and Al/Ti ratios. A decrease in Li and Cr indicate actual quartz dissolution. These elements are least affected by weathering (Al/Li and Al/Cr ratios decrease in secondary flints), suggesting relatively little quartz is dissolved. Depending on the Fe contents in the surrounding soil, new Fe (and Mn) may be precipitated in the voids that are formed after solution. If Fe-content is higher in the surrounding soil than in the flint, this will result in an increase of Fe in the flint.

[10] In theory it may be hypothesized that speed at which the weathering reactions occurred might have been higher at these localities. However, there are no indications, that suggest this, so for now I will assume that the period during which these flints were exposed to weathering is longer.

These results show that the concentration of trace-elements generally drops in weathered cherts, and only in case of high availability in surrounding soils may rise. Sheppard and Pavlish (1992) present an example of trace-element concentration rise in cherts due to high availability in surrounding soils. In their study of Pacific cherts, they attribute the increase of Al to bauxitic soils in which the flints were buried.

Considering the fact that the flints buried in soils, both at Blackman's Point as well as at Long Island, display the most significant changes, this weathering environment is more severe than the alteration on the beach. This can be related to a generally higher acidity, dissolving the calcite in the rock. The possible presence of humic acids in these soils, primarily responsible for quartz dissolution may have contributed as well to the general loss of most elements.

From this it is clear that in addition to a decrease of many trace-element values, the variation, measured by the RSD, increases in secondary flints. Apparently, individual rocks are altered differently depending on the time they are buried in soils. This means that on the one hand the weathering has a positive effect on discrimination, as secondary sources can be distinguished from primary ones originating from the same geological formation. On the other hand, it has a negative effect, as variation within a source becomes considerably larger, increasing the chance of overlap between sources.

On first sight, the Coconut Hall flints display a similar decrease in concentration of most of the elements related to clay minerals and calcite, as in case of the Blackman's Point material. More detailed comparison, however, reveals some differences, which cannot be explained by the weathering process described above. In the first place some of the flints still contain considerable quantities of carbonate material, indicated by high Ca-concentration and the presence of calcite crystals (tables 2.5-9). In correspondence with this presence of calcite is the significant lower number of voids visible than within the Blackman's Point rocks. This suggests markedly less dissolution of calcite, which may be an indication of a lesser degree of overall weathering, keeping in mind the generally higher solubility of calcite compared to quartz.

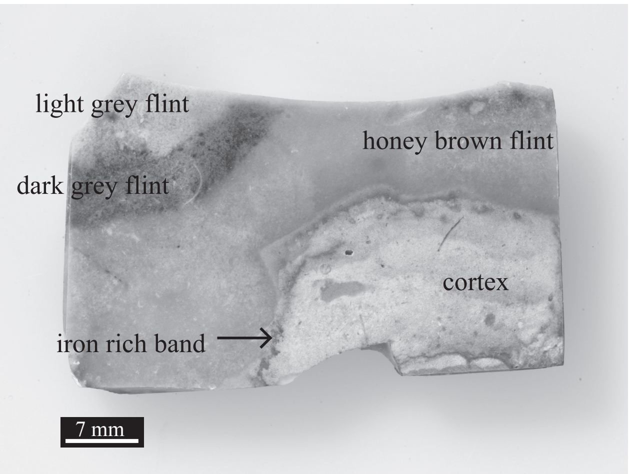
The second difference relates to the clay-associated elements. Although the concentration values of Al are in the range of those found in the Blackman's Point rocks, they vary more and more importantly, the relative amount in comparison with K is on average lower, suggested by low Al/K ratios. The Blackman's Point flints show a structural decrease of K relative to Al, when compared with the primary Antigua Formation flint sources. Some of the Coconut Hall samples, however, have Al/K ratios that are lower than any of the other Antigua Formation flints. This indicates a different original Al and K relation. If this latter characteristic is combined with the different quartz matrix fillings that some samples display, including high amounts of chalcedony, then the evidence suggests that the formation of the Coconut Hall flints had occurred in a slightly different geological environment, where K was more abundant than within the limestone of the other Antigua Formation sources.

With regard to the quartz matrix, the Coconut Hall flints resemble the Puerto Rican cherts, which also exhibit significant occurrence of chalcedony in the matrix (see figures 2.15 and 2.17). Considering the secondary nature of all these cherts, as well as the Coconut Hall flint, it is hypothesized that this chalcedony represents a secondary phase of silicification. This secondary phase may have altered original trace-element composition, making a sound comparison impossible.

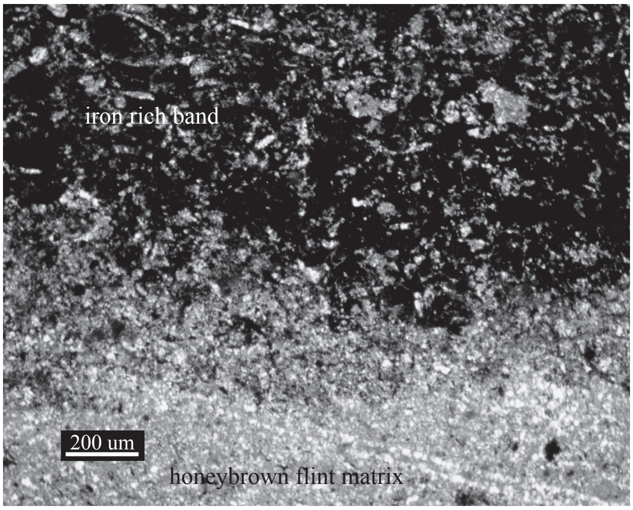
St. Kitts flints

The other definite limestone chert (flint) is found on St. Kitts. Earlier, I already assumed, based on similarity in macroscopic and microscopic features, that material from the different localities on the island probably were formed within the same limestone formation. The chemical data confirm this assumption. Trace-element concentrations of the different elements fall within the same range, and Al/K ratios do not vary between the sources, suggesting a similar clay origin (figure 2.23; see Appendix C).

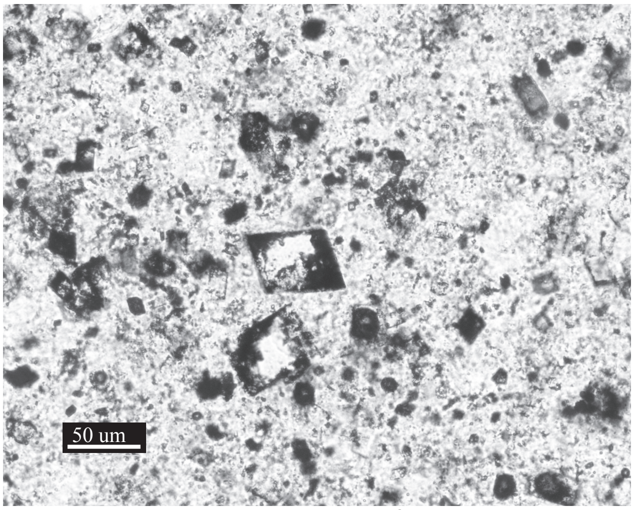
Only from Great Salt Pond, two poorly silicified, carbonate rich samples were analysed, and none were analysed for Sugar Factory Pier. Despite the secondary nature of the flints on St. Kitts, they do not exhibit clear signs of significant weathering, as some of the Antigua Formation flints do: (1) voids are not visible under the microscope, (2) no high Fe-concentration as a result of iron oxide precipitation is present, and (3) some samples still contain a lot of calcite, which is not expected if significant weathering had taken place. Two possible explanations may be suggested for this absence of alteration: (a) the low porosity of the quartz in matrix, which will make dissolution of quartz and subsequent weathering more difficult, or (b) the weathering that predominantly had taken place was within a beach environment, which appears to be a less destructive environment than certain soils, where the existence of humic acid is the primary cause for weathering.



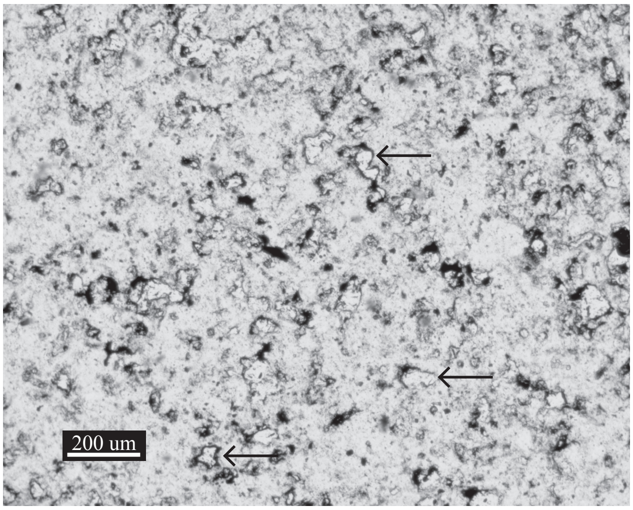
a. Long Island, cut flint sample ANLI-02.



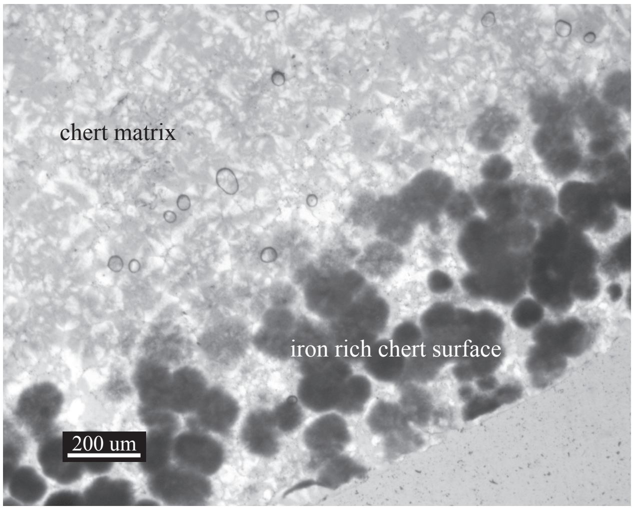
b. Long Island, iron rich band in sample ANLI-02 (CP).



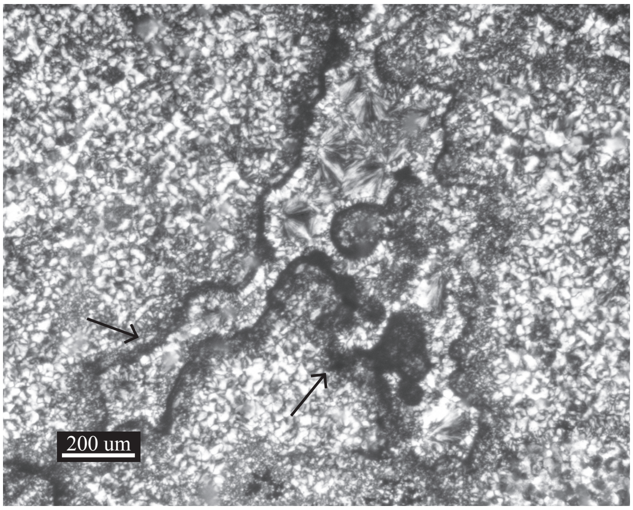
c. Blackman's Point, rectangular voids partially filled with iron oxides in sample ANBP-01 (PPL).



d. Long Island, small irregularly shaped voids (only three have been indicated by arrows) in sample ANLI-09 (PPL).



e. Moca, iron rich outer part of chert sample PRMO-04 (PPL).



f.Villa Taina, iron rich bands along vein boundaries in matrix of sample PRVT-02 (CP).

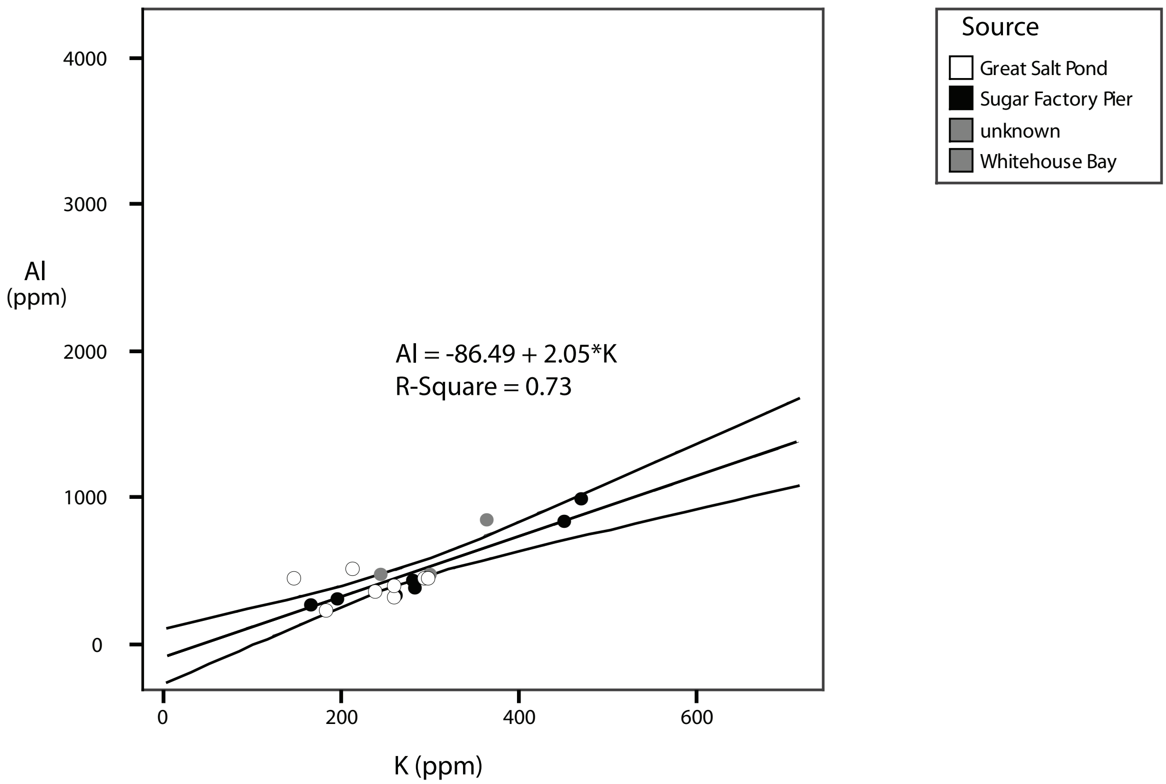


Figure 2.23. St. Kitts flints. Linear regression of Al by K with 95% mean prediction interval.

Comparing the St. Kitts material to the Antigua Formation flints, the following is noted (tables 2.5-9):
- Trace-element concentrations are in general lower than on Antigua, notably the elements Al, K, Li, Cr, Fe, and Ca, making the flints purer.
- The Al/K ratio is lower than within the Antigua Formation flints, indicating that clay minerals richer in K were responsible for the impurities in the St. Kitts flint. Considering the fact that terrestrial minerals likely are similar at St. Kitts, as igneous rock is similar, the higher K contents must be attributed to a larger portion of marine derived or authigenic minerals. Probably the illite and maybe the glauconite contents relative to smectite are higher in these flints.

These two facts relating to the flint from St. Kitts, that is lower trace-element concentrations and higher proportion of marine clays, may be inter-related. As authigenic marine clay-mineral formation is dependent on the availability of terrestrial minerals, a lower concentrated terrestrial input in the marine waters of St. Kitts will lead, in case of equal K-availability in marine waters, to a more complete conversion of the terrestrial clay-minerals into marine ones. This more complete conversion will result in a lower Al/K ratio.

Similar trends can be found among the northwestern European flints (Bush & Sieveking 1986; Sieveking *et al*. 1972). Although not mentioned by the authors, close inspection of their data reveals that flints with relatively high concentrations of clay related elements, for example those from the mine of Beer, have relatively higher Al/K ratios, than those with relatively low trace-element concentrations, most of the other mines (Bush & Sieveking 1986, 134 table 14.1; Sieveking *et al*. 1972). Al/K ratios fall in a similar range as the ones found in this study, suggesting environments of formation are similar between the Caribbean flints and these European ones.

Figure 2.22 (opposite page). One normal and five thin-section photos of different flints and cherts showing evidence of weathering. Thin-section photos in crossed polars (CP) and plain polarized light (PPL).

Antigua tuff cherts
Through comparison of the different flints, it is noted that variation between sources originating within a similar geological formation is small, although exceptions may occur. Variation between flints from different formations can be more significant, however. Furthermore, weathering may considerably alter the trace-element concentration values of particular flints, thereby increasing variation, both between as well as within sources. Knowing this, it is expected that general differences between flints formed within limestone, and cherts formed within tuffs will be significant as well. This has been confirmed. It has also become clear that variation among cherts formed within tuffs can be considerable.

Based on host-rock and chemical composition, the Central Plain and Basic Volcanic Suite cherts can be divided into two groups: (1) the Shirley Heights and Buckleys cherts, and (2) the Corbison Point and Dry Hill cherts.[11] The first group includes relatively pure cherts possibly formed from non-biogenic silica, and the second group represents bedded cherts in carbonate-rich and bioclast rich tuffs, possibly formed from biogenic silica.

Despite their pure appearance under the microscope in which only quartz is identified, the first group of cherts contains significant amounts of trace-elements, in particular the Shirley Heights locality. Within this group, the Buckleys chert data are only limited because the material gathered is not likely source material, given their artificial scattering. The data suggest that tuff at Buckleys may have been richer in carbonate material than the Shirley Heights cherts, as Ca is higher with respect to the concentration of Al. Furthermore, there is a correlation between Ca, Mg, Sr, and Ba. At Shirley Heights, a correlation between these latter elements is less evident, whereas a correlation between Al and Ca indicates that Ca is primarily associated with clays or tuffs.

A closer look at the Shirley Heights data reveals that a large group of elements is correlated (Al-Fe-Li-Ca-K-Na-Mg), which can be sub-divided into two groups, exhibiting an even stronger correlation (table 2.12). These two sub-groups are Al-Fe-Li-Ca on the one hand and K-Na-Mg on the other. With increasing Al-Fe-Li-Ca, the K-Na-Mg concentrations become higher as well; these latter ones increase proportionally less, however. This is indicated by different ratios: Al/Fe, A/Li, and Al/Ca remain constant with increasing concentration of Al, whereas Al/K, Al/Na, and Al/Mg become higher when Al increases. Both groups apparently represent two different mineral fractions from which they originate.

As already pointed out, igneous rocks on Antigua are calc-alkaline in nature, with relatively abundant Ca, Fe and Mg in addition to Al (chemical data from Christman 1972). Except for Mg, the element composition of the igneous rocks correlates well with the first group of elements. As I specified above, Mg may have a major marine origin (chlorite), in addition to an igneous one. The close similarity between both sets of elements suggests that they may directly originate from the tuff. On the other hand, K is rare among the igneous rocks, and its origin is therefore likely marine in the form of clays, such as illite (K). Combining this, it can be concluded that both cherts were likely formed within a carbonate poor (Ca is low compared to the flints, for example) marine deposition of tuffs and clays, which is notably different from the carbonate pure environment of the Antigua Formation flints.

Difference in solubility may explain the proportional differences of both fractions within the low trace-element and high trace-element samples. Apparently, the clay fraction has a lower solubility grade, as is suggested by proportionally higher concentrations of K, Mg, and Na compared to the Al, Fe, Ca, and Li concentrations (expressed by low A/K, Al/Mg, and Al/Na) in the relatively pure cherts. In a more pure chert the silica has replaced the host-rock to a greater extent.

The cherts from Corbison Point and Dry Hill resemble the Antigua Formation flints more in their trace-element composition, notably in their high Ca and Mg concentrations (tables 2.5-9). This is expected given their carbonate rich environment of formation. Still, differences are apparent. In particular, the relatively high variation within the Corbison Point chert is striking. I already noted that the Corbison Point cherts can be divided into four different varieties based on similarity in microscopic characteristics, as well as chemical composition. These four varieties each originate within one of the different beds identified at the Corbison Point rock section. Comparison of the chemical data shows that variation within each variety (so, within each bed) was low, whereas variation between beds is high with regard to Al and Li concentration and Al/K ratios, suggesting a different mineral suite origin for each bed.

The most striking differences are tabulated in table 2.13. The most extreme varieties are represented by a calcareous poor and Al-K-Na poor pure chert, with high Al/K ratios on one end and a bioclast rich, calcareous rich, chert with low Al/K

[11] The limited data obtained on the Willis Freeman chert are left out of this discussion, as the available results do not provide any clear patterns in the form of correlated groups of trace elements, hampering the understanding of trace element origin. Additional sample taking in the future, combined with an extensive series of chemical analyses, should clarify whether this lack of correlation is real or whether it is a result of poor sampling.

sample number	tuff group				clay group			tuff group			clay group		
	Al	Fe	Li	Ca	K	Na	Mg	Al/Fe	Al/Li	Al/Ca	Al/K	Al/Na	Al/Mg
C-ANSH-01	4168.2	198.5	14.2	489.7	649.8	576.4	62.7	21.0	294.4	8.5	6.4	7.2	66.5
C-ANSH-04	2555.3	146.0	9.6	240.0	444.7	420.1	24.7	17.5	266.7	10.7	5.8	6.1	103.5
C-ANSH-09	2192.1	93.6	9.1	227.2	458.9	410.4	39.8	23.4	241.2	9.7	4.8	5.3	55.0
C-ANSH-11	1735.3	71.1	6.7	229.2	374.6	357.6	36.1	24.4	258.2	7.6	4.6	4.9	48.1
C-ANSH-03	1660.0	93.1	8.1	254.0	331.4	331.3	45.5	17.8	206.2	6.5	5.0	5.0	36.5
C-ANSH-06	910.3	35.2	3.4	106.8	262.8	341.5	26.6	25.9	270.9	8.5	3.5	2.7	34.3
C-ANSH-12b	278.9	18.1	1.4	123.1	93.9	97.2	8.2	15.4	193.7	2.3	3.0	2.9	34.0

Table 2.12. Concentration values (in mg/kg (ppm)) and ratios of main correlated trace-elements in Shirley Heights chert. Note that samples are tabulated in decreasing order of Al.

ratio and moderate Al-K-Na concentrations on the other end. These chemical data suggest alternation between one period of low carbonate and high clay and tuff deposition resulting in a proportionally high terrestrial input, and consequently a high Al/K ratio (variety C)[12], and periods of high carbonate deposition and relatively lower, but varying terrestrial inputs, with lower Al/K ratios (varieties A, B, and D). Within these latter carbonate chert varieties, it is noted that they follow the trend observed for the limestone flints: the sequence from D → B → A corresponds with increasing Al concentrations, indicating higher terrestrial input, resulting in higher Al/K ratios. Close comparison with the limestone flints, however, shows that the Al/K ratios within the Corbison Point cherts on average are higher, given a certain level of Al-concentration.

In this regard, the Dry Hill cherts exhibit considerably less variation; the samples basically resemble the B and D varieties of the Corbison Point chert in microscopic features and chemical composition. However, it has to be pointed out that the Al/K ratio generally is higher than most of the B and D cherts at Corbison Point. This similarity suggests that although the beds exposed at Dry Hill correspond with beds at Corbison Point, the individual beds are not completely similar.

Unlike minor variation between Antigua Formation flints from different localities, cherts within the Central Plain Group and Basal Volcanic Suite exhibit considerable variation, even within single localities that only expose small portions of a formation. At some localities variation is continuous such as Shirley Heights, corresponding with the degree of silification, while at others it is discrete, corresponding with different beds, such as Corbison Point. This contrast between the limestone flints and the tuff cherts may well be explained by the different conditions under which they were formed. The origin of the silica plays a decisive role in this respect.

number		type	Al/K	Al	K	Na	Li	Ti	Ca	Mg
ANCP-20	bioclast poor and carbonate rich	D	1.78	51.76	29.02	252.78	0.93	12.02	8828.38	238.62
ANCP-10 (pri)	pure dirty chert	D	2.27	58.18	25.58	356.56	0.77	8.43	8714.55	220.78
ANCP-02	bioclast rich and carbonate rich	B	3.40	773.59	227.34	488.46	17.22	113.53	695.73	96.00
ANCP-12 (pri)	chert	B	3.52	831.65	236.35	1328.97	12.32	39.26	37884.83	693.99
ANCP-13		B	3.70	570.29	154.08	1299.00	11.36	33.43	30698.85	554.58
ANCP-11.2 (pri)	bioclast rich chert with varied	A	4.30	1611.41	374.63	1128.09	25.40	80.17	9579.71	267.19
ANCP-11.1 (pri)	carbonate concentrations and	A	4.45	1551.94	348.72	1077.58	23.81	82.63	6434.20	205.41
ANCP-21	high terrestrial input	A	4.75	1393.51	293.44	641.92	20.97	107.94	329.58	59.60
ANCP-01		A	4.95	1871.12	378.17	672.78	28.08	85.98	340.76	46.60
ANCP-05		A	5.54	2332.44	420.80	861.35	33.73	110.10	437.77	99.01
ANCP-04	bioclast poor and carbonate poor	C	6.34	169.98	26.80	103.89	1.58	10.90	54.91	54.56
ANCP-06	pure chert with low trace-element	C	6.70	81.08	12.11	52.78	< d.l.	< d.l.	18.27	14.64
ANCP-03	concentrations	C	6.79	148.57	21.87	156.82	1.86	23.98	80.24	61.57

Table 2.13. Sub-varieties of chert based on microscopic as well as chemical characteristics within Corbison Point chert. Trace-element concentrations in mg/kg (ppm), “pri” denoted primary sample taken from one of the beds.

12 Note that Ca is correlated with Al, and that the Ca/Mg ratio is much lower than in the carbonate rich varieties. This suggests that Ca is primarily associated with the clays and tuffs, and not with a carbonate fraction.

Nodular chert in limestone derives its silica from small organisms, consisting of opal (amorphous silica) such as diatoms, or radiolarians. These fine organisms will be only deposited in a low-energetic marine environment (Zijlstra 1994). Usually, this is a protected basin, which receives little terrestrial inputs (clays, tuffs, or detrital minerals). This means that these environments are relatively pure in carbonate (silica concentration may even be low as well), which makes them very similar and leaves little room for variation.

In contrast cherts in tuffs or volcanic rocks derive their silica from the Si abundantly present in the tuff or volcanic host-rock. Although the specific mechanism by which silicification occurs has not been fully understood, it has become clear that host-rock can vary considerable in composition, with respect to elements such as Al, K, Mg, Ca, Fe, and Na. As a result, the chert may differ in trace-element composition as well.

Puerto Rico cherts

A proper understanding of the trace-element composition of the Puerto Rican cherts is complicated by their unclear geological origin. From the ICPAES analysis it is clear that the different localities share a number of features (table 2.5-9): (1) a very low Ca/Mg ratio, (2) low Al-K-Na concentrations, (3) high Fe and Mn concentrations for a large number of samples, and (4) a generally poor correlation between the different elements. These latter three characteristics suggest that chemical weathering has affected the rocks. This is already evident from the general light colour of most cherts, and the microscopic identification of clear concentrations of iron oxide, notably in the outer rim of most samples. The formation of voids, similar to some of the secondary Antigua flints, had not occurred, however. Combined with the fact that calcite is not present in the Puerto Rico cherts, this again supports the notion that within the Antigua Formation flints these visible voids primarily have to be related to calcite dissolution.

Table 2.14 lists some specific characteristics for each location individually. It has to be stressed again that in comparison to the Antigua Formation flints, for example, the correlation is generally weaker, or only applies to a part of the samples from within the source.

Summary

Close comparison of lithic sources originating from the different islands shows that they vary in their trace element composition if they originate from different host-rocks. In particular, the concentration ratios of elements associated with a clay, tuff, and carbonate fraction exhibit diversification, and suggest the presence of different types of impurities (figure 2.24). Furthermore, the results show that inter-source (between) and intra-source (within) similarity can be considerable for flint varieties originating within the same limestone formation. In particular, constant Al/K ratios suggest that the clays, from which a substantial portion of the elements originate, are the same.

Cherts formed within tuffs generally vary more, both in concentration values and the type of terrigenous input, as suggested by varying Al/K ratios. This variation is not only evident between sources, but may be even the case within a single source. This can occur if different beds are exposed, which were formed in varying host-rock types, as is the case at Corbison Point and Dry Hill. Furthermore, the data suggest that weathering may have a significant influence on the original trace-element composition. Such is particularly evident for cherts and flints that have been buried in soils for long periods. Beach environments, where salt water is the primary weathering agent, have less significant effect. The more severe weathering characteristic of soils can be attributed to significant calcite dissolution, making the flints more porous and increasing the quartz surface exposed to weathering agents. This larger surface exposure will increase the weathering rate of quartz as well as impurities in it by available humic acids.

Overall, different forms of weathering have a negative effect on source discrimination. Weathering produces high variation among concentration values within sources, making the chance of overlap between sources more likely. In specific cases, however, it may differentiate localities, which were originally similar. This only accounts for sources where all available material, spatially constrained, has been exposed to a similar weathering environment for a considerable period, as is the case at Blackman's Point.

Source	Specific features
Cerillos	* high but varied Al/K ratio
	* very low Ca/Mg ratio
	* Fe-Mn-V correlation
	* Mg-Li correlation
	* Al-Ti correlation
Villa Taina	* varied, but on average high Fe concentration
	* high but varied Al/K ratio
	* Al-Fe-V-Zn correlation
	* Ca-Mg correlation
Moca	* high Fe concentration
	* Al-K-Na-Ti-Cr-Sr correlation: clay/tuff
	* P-Fe-Zn correlation: iron minerals
Las Palmas	* varied, but on average low Fe concentration
	* Al-Fe correlation
	* Ti-Mn correlation
	* Ca-Mg correlation
Pedernales	* low Fe concentration
	* Al-K-Na correlation
	* Ca-Mg correlation

Table 2.14. Puerto Rican cherts. Specific chemical characteristics for each source.

2.5 Discrimination of sources

2.5.1 Discriminant Analysis

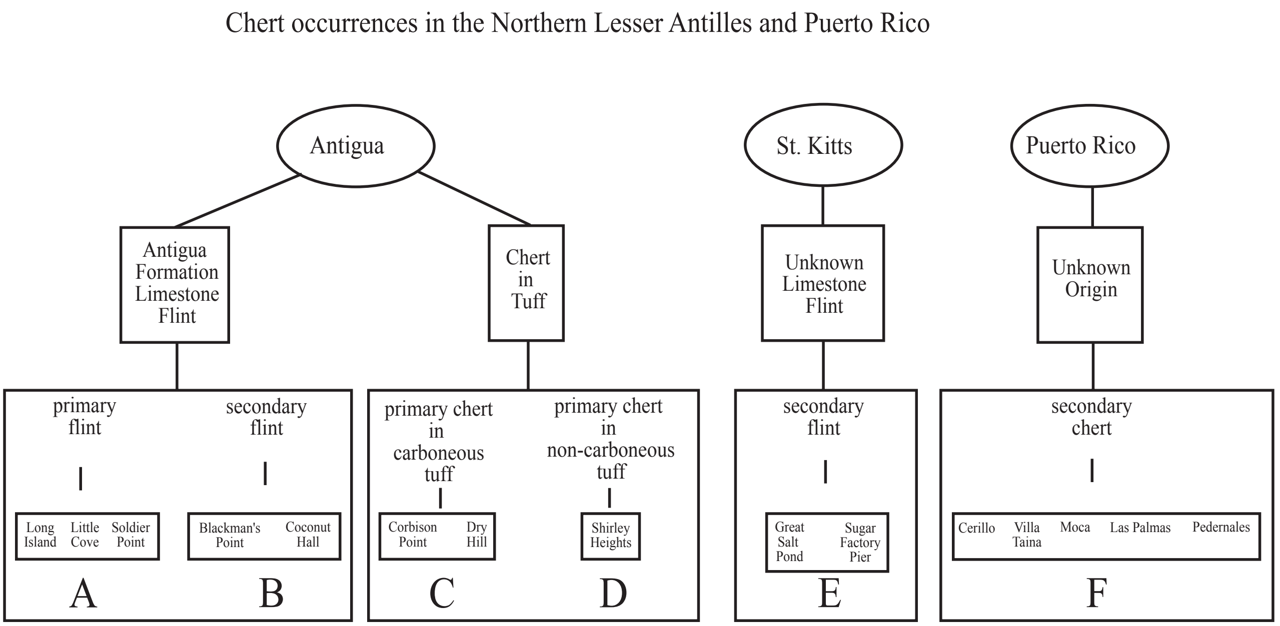
Source characterisation and discrimination using trace-element concentrations has become a common method within archaeology (Cackler *et al.* 1999b; Craddock *et al.* 1982; De Bruin *et al.* 1982; Glascock *et al*. 1998; Luedtke 1978, 1979, 1992; Shackley 1998; Sieveking *et al*. 1972; Sieveking & Thompson 1986; see Church 1994 for an overview). The possibility of obtaining a large number of variables (the concentrations of the different elements) as well as their quantification (the concentration values), gives a great advantage over traditional macroscopic and microscopic techniques. These latter techniques often involve a more limited number of variables, which are typically hard to quantify.

Acquisition of numerous and quantifiable variables makes it possible to employ multi-variable statistical techniques to differentiate sources and provenance artefacts. Following Luedtke (1979), who tested different identification methods, the application of Discriminant Analysis is most suited to this purpose. The recurrent use of this technique supports this notion (Craddock *et al*. 1983; De Bruin *et al.* 1972; Glascock *et al*. 1998; Sieveking *et al*. 1972).

Keckla (1980, 7) defines Discriminant Analysis as "a statistical technique which allows the researcher to study the differences between two or more groups of objects, with respect to several variables simultaneously." In relation to this study, the sources of chert material are the groups, and the different trace-element concentration values represent the variables. This technique can be applied in two different ways: (1) Descriptive Discriminant Analysis is used in interpreting group differences; and (2) Predictive Discriminant Analysis in classifying (assigning[13]) cases to groups. The latter application has been widely used in provenance studies for stone materials.

In short, Discriminant Analysis (DA) determines which factors contribute most to group separation. It identifies functions, called canonical discriminant functions, that are linear combinations of the original variables. These functions maximally enhance group separation. The classification technique of DA calculates a centroid for each group, which is the mean value in multi-dimensional space based on values obtained from the canonical discriminant functions. It then compares the distance of the canonical value of an unknown case (an artefact for which one wants to identify the source) to the centroids of the different groups. This distance is called the Mahalanobis distance. The Mahalanobis distance (D^2) is defined as the "squared Euclidean distance between a group centroid and an individual specimen divided by the group standard deviation in that direction" (Glascock *et al*. 1998). The artefact will be assigned to the group for which the D^2 is smallest.

[13] In this chapter I use the word "assign" for placing an unknown case (i.e. artefact) within a pre-defined group (a source) and the word "classify" for grouping a number of cases based on predefined criteria. Confusingly, in predictive Discriminant Analysis the term classify is often used for assigning unknown cases to known groups (e.g., Duarte Silva & Stam 1995).



A & E: Correlated Al-K-Ti-(Fe); Constant Al/K ⟶ terrestrial and marine clays
High but varied Ca-concentration ⟶ carbonate

B: Weakly correlated Al-K-Ti; Varying Al/K ⟶ terrestrial and marine clays, which partly have been dissolved
Low Ca-concentration ⟶ dissolved carbonate; Varying but high Fe ⟶ iron from surrounding soil

C: Varied Al/K ⟶ terrestrial, marine clays and tuff in varying compositions by layer
High but varied Ca-concentration ⟶ carbonate

D: Correlated Al-Fe-Li-Ca group ⟶ tuff
Correlated K-Na-Mg group ⟶ marine clays

F: Poorly correlated elements, generally low concentrations; Fe may high ⟶ weathering
Origin of the elements is unclear; no carbonate

Figure 2.24. Overview of flint and chert geochemistry in the Lesser Antilles and Puerto Rico.

Glascock *et al.* (1998, 31), following Keckla (1980) and Hughes (1986), have listed the statistical assumptions, that need to be fulfilled when the classification aspect of DA is used:
“(1) there are two or more groups;
(2) there are at least two observations in each group;
(3) the number of discriminating variables must be at least two less than the total number of specimens;
(4) the discriminating variables are measured at the interval level;
(5) the discriminating variables must not be linear combinations of other discriminating variables;
(6) each group is drawn from a sample population with a multivariate normal distribution on the discriminating variables; and
(7) the variance-covariance matrices for each group must approximately be equal.”

2.5.2 Results

In this study, 12 elements were used for the discrimination of sources and assigning artefacts to sources, as they proved to be above the detection limit in most cases and produced relatively precise results. They include the following:
Lithium (Li), Sodium (Na), Potassium (K), Magnesium (Mg), Calcium (Ca), Barium (Ba), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), and Aluminium (Al).
Of these, V, Cr, and Mn concentrations were occasionally below the detection limit, and this missing value was given an arbitrary value of 10% lower than the detection limit (see Rock 1988 for how to handle missing values). Five samples from five different sources were omitted, as they possessed outliers for different elements.

In this study, the first five requirements as specified and listed by Glascock *et al.* (1998) are met. Absolute values of some elements, however, are not always distributed normally. Therefore, a log-transformation of each value was performed to obtain a distribution more similar to a normal one, following earlier studies relying on compositional data (Glascock *et al.* 1998; Luedtke 1979; De Bruin *et al.* 1972). Furthermore, the variance-covariance matrices are not equal for all sources. In particular, the Corbison Point and Shirley Heights cherts are different in this respect from the Antigua Formation flints. This inequality may have consequences for the final assignment of the artefacts.

To evaluate how well sources in this study are discriminated, in the first instance only the source samples were entered and tests were performed on classification results, following Glascock *et al.* (1998). Luedkte (1979) named three different types of errors that occur when assigning artefacts to sources. Her type one error corresponds with assignment of a case to a source when it is actually from another source (figure 2.25). The SPSS computer program (version 9.0 for Windows) provides the option of treating source samples as unknown cases and this can be used as an estimator of how well the elements separate the different sources, and the rate of successful assignment. This can be considered as an estimator of type one error. There are two "classification" possibilities in SPSS: (a) one source sample at a time is treated as unknown, when all information is used in separating the sources, including the information on this "unknown" sample, or (b) one source sample at a time is treated as unknown, when information on this sample is not used in the source separation. This latter type of classification is referred to as cross-validation in the SPSS program, and it also called the leave-one-out, or jack-knife method (Duarte Silva & Stam 1995; Glascock *et al*. 1998)). According to Duarte Silva & Stam (1995, 301-304), the first estimator of the correct classification rate is optimistically biased. They prefer the cross-validation type of classification. This one, however, is a poor estimator if small sample sizes have to be dealt with, which is the case in this research.[14] Still, Glascock *et al*. (1998) used this latter option in their provenance study of Meso-American obsidians to see how well the different sources were discriminated.

The other types of error are each other's opposites. Error 2 is defined as assigning an artefact to a source not included in the study when in reality it belongs to a source within the study (see figure 2.25). Error 3, then, is defined as assigning an artefact to one of the sources within the study when it actually is from a source not part of the study (see figure 2.25). Error 3 is considered by Luedtke as "potentially the most serious type" (1979, 751) because the number of these unknown sources can be significant. Her study on comparing different identification techniques confirms this. The difficulty with studying these latter two errors lies in the way the classification aspect of DA functions. The analysis does not consider the possibility of a source outside the study and will always assign an artefact to one of the sources included within it. One way of overcoming this problem is by defining an arbitrary value of the Mahalanobis distance as the cut-off point beyond which artefacts are classified as unknown. However, the difficulty remains, that a too high D^2 value, will result in a large error 3 type, whereas a value too low will result in a large error 2 type.

Different levels of source discrimination can be applied in this study. In the most detailed level, each locality on each island is treated as a separate source (group), resulting in 15 groups. A more general level puts the sources into larger groups on the basis of their shared geological history, e.g. all sources from the Antigua formation in one group, all the Central Plain sources in one group, etc. The most general level treats the different islands each as separate groups.

Of course, the most specific level would be the most desirable level, in particular if lithic procurement behaviour by the inhabitants of the source islands themselves is under investigation and there are indications that utilized cherts may have come from different islands. In such a case, it may be meaningful to differentiate between different regions across an

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[14] The leave-one-out principle is one specific type of cross-validation. Duarte Silva & Stam (1995) state that a common practice of cross-validation in the social sciences is to divide the groups (sources) into two, after which one half is used to determine the discriminant functions, and the other half is used as a test sample which is treated as unknowns. This, off-course, can only be done when sample sizes for groups are considerable.

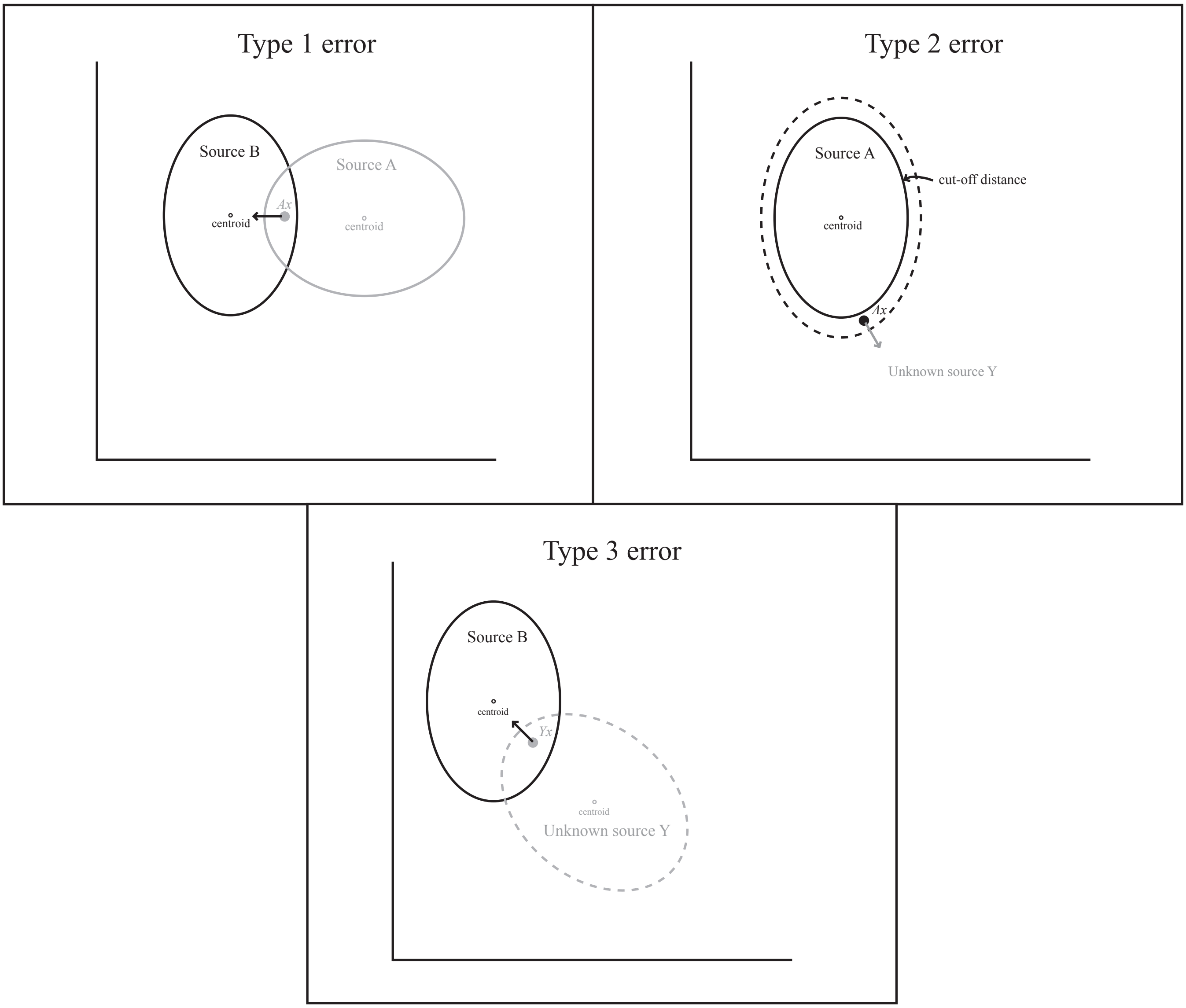

Figure 2.25. Graphic depiction of error types according to Luedtke (1979).

individual island. On a larger scale, however, if the regional distribution of chert materials among the different islands is at issue, the provenance only specified to the island level may well be sufficient.

I tested these different levels on their correct assignment rate using both classification procedures in the SPSS program. For each level, I searched for the element combination, that gave the highest rate, by the backward stepwise method, as described by Keckla (1980). It appeared that using all 12 elements did not necessarily produce best results in most cases, again supporting the notion that intra-source variability is high for some elements. Furthermore, it should be emphasized that high intra-source variability will significantly lower the correct assignment rates in the case of leave-one-out cross-validation, in particular for sources characterized by low number of samples.

The most detailed level of source separation using cross-validation classification in the SPSS program shows that the correct assignment rate is relatively poor, a little above 73%. Different researchers working on northwestern European flints found similarly low or even lower success rates (Craddock *et al*. 1983; De Bruin *et al.* 1983). This poor assignment rate compared to, for example, obsidian studies (see Glascock *et al*. 1998) can be attributed to large intra-source variation of some sources in particular and low inter-source variation in general in the case of cherts and flints.[15]

Looking in detail at assignments within this study, many of the incorrectly assigned samples are assigned to sources with a similar geological context. Many of the Dry Hill samples, for example, are assigned to the Corbison Point locality. Furthermore, it is noted that the particular sources from Puerto Rico and St. Kitts give poor results. Many of the samples from a locality on these the islands are misclassified to another source on the same island, showing that for these two islands inter-source compared to intra-source variation is low. If each of the islands is studied separately using discriminant analysis, assuming that chert can only come from this island, St. Kitts gives a correct assignment rate of only around 60% for the Great Salt Pond and Sugar Factory Pier localities. This means that geo-chemical characterisation only barely provides better assignment results than randomly grouping the artefacts to one of the two sources, which would give a rate of 50%. Above I noted that the St. Kitts flint is similar in its macroscopic and microscopic appearance, suggesting a common origin. The geochemical results further support this. In statistical terms both sources can be nearly considered as two samples derived from the same population. Consequently, it means that St. Kitts flint cannot be assigned with any accuracy to either of the two localities.

For Puerto Rico, the situation is different. Although the correct assignment rate is low (74%), the fact that we are dealing with 5 sources makes this 74% significantly higher than 20% that would be obtained when randomly grouping the samples. Furthermore, if different discriminant analyses are performed in which sources are compared two at a time, almost 100% correct assignment can be achieved for almost every pair. This clearly supports the existence of differences between sources despite the low overall rate of correct assignments. Still, determining the exact provenance of Puerto Rican artefacts on the basis of geo-chemical characterisation will be inaccurate for most localities. Accuracy will be improved if, a priori, localities are excluded on the basis of macroscopic features or unlikely use.

On Antigua, source assignment is also not perfect. However, it is evident that most misclassified samples are ascribed to a source, that can be considered similar in geological terms (see above). Discrimination in Antigua on a broader scale, in which sources are grouped following the different geological regions, roughly between the northeastern and southwestern parts, produces better results. However, a 100% correct assignment rate cannot be obtained. This is partly due to the broad variation within the Corbison Point chert. Given discontinuous variation between different layers within it, additional sample taking in the future will probably make it possible to divide the Corbison Point source into several sub-sources, each corresponding with a single layer. These sub-sources, treated as separate groups, will probably together exhibit less overlap with other Antigua sources than grouping them as one source.

Considering this poor correct assignment rate on a source specific level, the next step is to see how well the three islands can be discriminated. It appears that approaching this problem using two steps produces the best results. By first discriminating Puerto Rico from the two Lesser Antillean islands, a 100% correct assignment rate is nearly obtained. One sample from Puerto Rico out of 46 samples is assigned to the Lesser Antilles, and two samples from the Lesser Antilles out of 96 samples in total (one from Antigua and one from St. Kitts) are assigned to Puerto Rico. The next step of discriminating Antigua from St. Kitts results in two St. Kitts samples assigned to Antigua, while all Antigua samples are correctly identified, corresponding with an 95.7% overall correct classification rate.

The problem with applying discriminant analysis in this manner is that errors made during the first analysis will be of significance during the following analyses. This means that the total error during the last analysis is the sum of all errors made during the earlier ones, plus the last one. However, it appeared that the overall correct assignment rate is higher in the case of doing two separate analyses than separating the three islands during a single analysis.

Looking at discrimination within the island of Antigua, a similar series of discriminant analyses was attempted, which will ultimately produce higher rates of correct assignment. During each such analysis, source groups are separated from each other, reducing the number of sources to be discriminated in the next analysis. So, in the first analysis the Shirley Heights source can be separated from the rest with 100% accuracy. In the following analysis, the Dry Hill and Corbison Point sources discriminate from the Antigua Formation flints. The Antigua Formation flints can then be divided into the Long Island source, the pair of Little Cove and Soldier Point, and the pair of secondary Antigua Formation flints from Blackman's Point and Coconut Hall. Only during the last round of analyses problems arose in distinguishing the Little

[15] This may well by explained by the different environments of genesis between both rock materials. In the case of obsidian, sources usually correspond with specific volcanic outburst events. These events generally vary significantly in chemical characteristics, even between events from a single volcano. Furthermore, obsidian contains higher concentrations of trace- and rare-earth elements in general than does flint, which makes the possibilities of finding discriminating variables higher for obsidian.

Cove from the Soldier Point, the Blackman's Point from the Coconut Hall, and the Dry Hill from the Corbison Point flints. Correct assignment, however, still is above 90% for the first pair, and even above 95% for the latter two cases. Furthermore, the inability to completely distinguish Corbison Point from Dry Hill has less significant archaeological implications as both localities are only at 1.5 km distance from each other along Antigua's western coast. On the other hand, the different analyses show that when it would be possible to exclude certain origins a priori, very accurate assignments may be given for the cherts and flints on Antigua.

This discussion shows that correct assignment cannot be achieved on a 100% basis for all sources. This analysis includes a number of lithic localities, that were not certainly exploited during the past. For a small number of other sources, in particular the Long Island source, clear evidence of exploitation in the form of flake scatters has been identified. Furthermore macroscopic inspection of a number of artefact collections from sites in the near region had already demonstrated that the Long Island source might have been of great significance during the pre-Columbian era, as these artefacts strongly resemble the source material. In the next few chapters I demonstrate that Long Island actually was the primary fine-grained material for making flake tools within the northern Lesser Antilles. Given this a priori knowledge and the fact that all sources are difficult to discriminate, I have approached the problem of discrimination and assignment differently, following a procedure in which the Long Island source obtains a central role. The primary question asked is: can a way be found to discriminate Long Island from other flint and chert sources, with a 100% percent accuracy using cross-validation as the estimator? During such a procedure, all Long Island source samples have to be assigned to Long Island and all non-Long Island source samples have to be assigned to one of the other sources or source groups. Correct assignment to the other sources is desired, but not of primary importance. It appears that grouping the sources, based on similarity in geological formation and post-formation history as specified above, produces best results (figure 2.26).

In this grouping, a division is made between the primary Antigua Formation sources (LC and SP), the secondary Antigua Formation sources (BP and CH), the Central Plain Tuff cherts (DH and CP), the Basal Volcanic Suite cherts (SH), the sources from St. Kitts (GSP and SFP) and the sources from Puerto Rico (CE, VT, MO, LP, and PE). Table 2.15 lists the assignment results using these groupings. From this it is clear that almost a 100% correct assignment rate can be obtained for the Long Island samples, and that none of the other source samples are assigned to Long Island. Only one Long Island source sample is assigned to the other primary Antigua sources, which is a likely mistake considering their similar geological origin. A second analysis then separates the Long Island source from the two other primary Antigua Formation flint sources. Using only four elements, a 100% correct assignment rate is obtained.

This procedure also allows a better evaluation of the type 2 and 3 errors, as only the Long Island source is relevant. The Mahalanobis distance values of the Long Island source samples do not vary much and are relatively low, which is in contrast to the high variation among some of the other sources. This low variation suggests that the chance of finding either significant amounts of type 2 or 3 errors are unlikely. Therefore, taking the highest value as cut-off point may in this case provide a means of avoiding samples from unknown sources (not included in the study) being assigned to the Long Island source. Such a source is likely situated within the Antigua Limestone Formation, given the similarity in trace-element composition of the primary sources from this formation.

As the above discussion shows, this method does not provide an absolute 100% certainty with regard to correctly assigning the source samples to each source, clearly indicating that the geochemistry of the different cherts overlap. Therefore, it is recommended that in each case of matching an artefact, sources preferably need to be excluded beforehand if possible, to minimize the chance of incorrect assignment. For example, in the case of dark coloured cherts or flints, the white to light grey coloured Shirley Heights source can be excluded.

Close inspection of the D^2 values within this source study shows that some source samples have high values, suggesting that these sources are varied and these samples lie at the extremes of the within-source distribution. These D^2 values, for example, can be higher than some other samples' "second source" D^2 values (that is, the value of the Mahalanobis distance to the second best source, which is often tabulated in SPSS next to the first source D^2). If one of the sources, of which some samples have low "second source" D^2 values (for another source), has not been included in this study and if these high D^2 values of the group of samples mentioned in the beginning are used as the cut-off points, it is immediately clear that there will be a number of type 3 errors. On the other hand, if the low "second source" D^2 values guide the choice of the cut-off point, there will be a number of type 2 errors. Therefore, it is likely, considering the fact that not all sources are included, that if a specific D^2 value is chosen, either considerable type 2 or 3 errors will arise in this study.

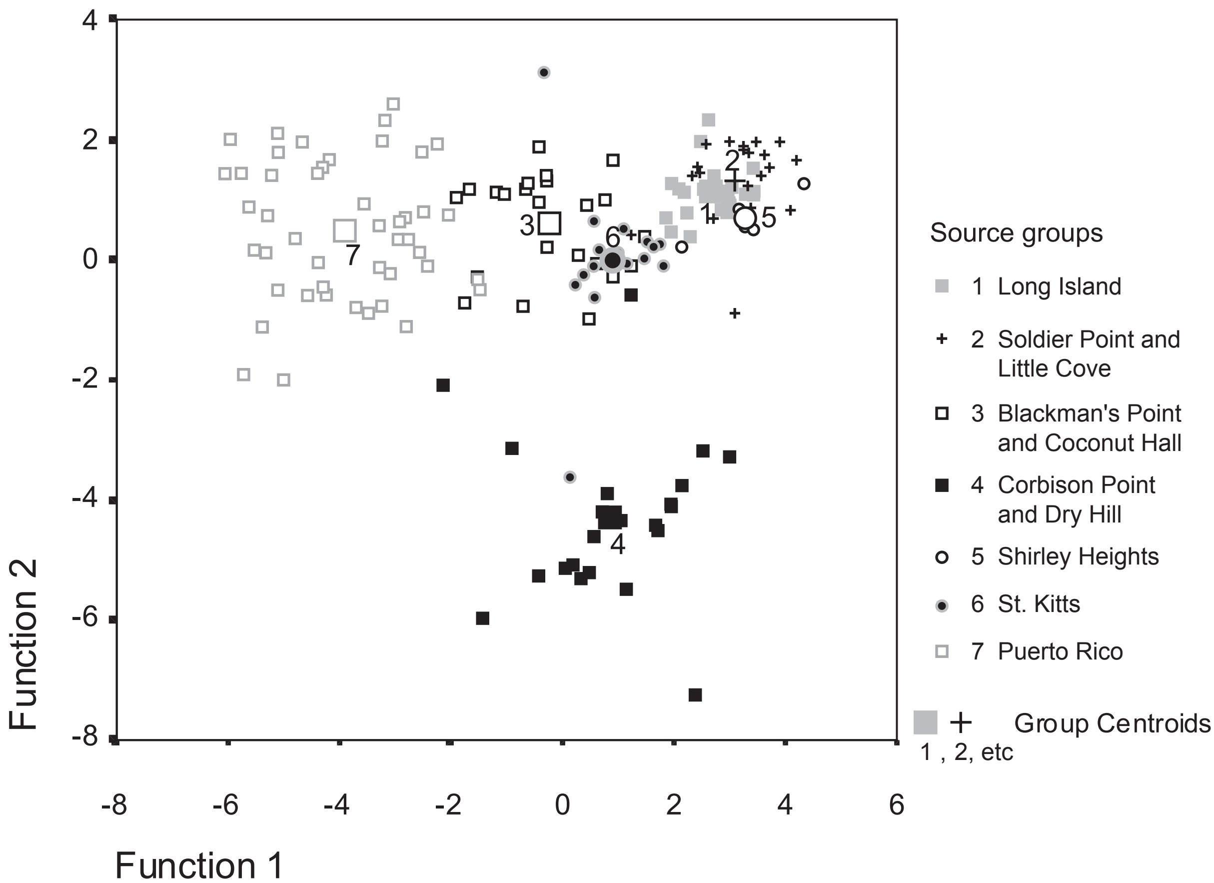

Figure 2.26. Scatter plot of the first two caniconal discriminant functions by source groups.

2.6 Source identification of artefacts.

2.6.1 Introduction

During the analysis of a number of collections of excavated lithic artefacts from habitation sites on the different islands of the northwestern Lesser Antilles and Puerto Rico (see Chapters 3 and 5 for the complete list and description of the artefacts), chert artefacts were grouped into distinct varieties on basis of their macroscopic similarity. Usually, characteristics of each variety were defined on the basis of the different source groups, which are incorporated in this study. This means that if the macroscopic characteristics of a number of chert artefacts, or simply just one artefact, correspond with those characteristics of a source group they are grouped to a chert variety[16] named after the source locality, e.g., Little Cove flint. In case of highly variable source groups, sub-varieties can be distinguished, e.g., Coconut Hall flint A, corresponding with the grey flints, and Coconut Hall flint B, corresponding with the brown flints. So, on the basis of macroscopic similarity, artefacts had already received a source assignment.

In case artefacts do not match these pre-defined source varieties, or similarity with these varieties is questionable, they were grouped into a new variety. Grouping[17] and defining unknown chert varieties is an arbitrary process, which largely depends on the number of artefacts exhibiting similarity and the variation similar chert pieces exhibit. When one encounters unknown varieties, it is important to make a distinction between a variety based on similarity among artefacts and

[16] Luedtke (1992, 6) uses the term chert type for a chert variety that originates from a single source location.

[17] I use the word grouping here, instead of classifying, because defining the variety occurred after putting the artefacts together, and not a priori, as should have been the case during classification.

Classification Results			Predicted Group Membership						
		Long Island	Little Cove and Soldier Point	Blackman's Point and Coconut Hall	Corbison Point and Dry Hill	Shirley Heights	St. Kitts	Puerto Rico	Total
Original	Count								
Long Island		21	0	0	0	0	0	0	21
Little Cove and Soldier Point		0	23	0	0	0	0	0	23
Blackman's Point and Coconut Hall		0	0	22	0	0	1	0	23
Corbison Point and Dry Hill		0	0	1	20	0	1	0	22
Shirley Heights		0	0	0	0	7	0	0	7
St. Kitts		0	2	0	1	0	15	0	18
Puerto Rico		0	0	0	0	0	1	45	46
	%								
Long Island		100.0	0	0	0	0	0	0	100.0
Little Cove and Soldier Point		0	100.0	0	0	0	0	0	100.0
Blackman's Point and Coconut Hall		0	0	95.7	0	0	4.3	0	100.0
Corbison Point and Dry Hill		0	0	4.5	90.9	0	4.5	0	100.0
Shirley Heights		0	0	0	0	100.0	0	0	100.0
St. Kitts		0	11.1	0	5.6	0	83.3	0	100.0
Puerto Rico		0	0	0	0	0	2.2	97.8	100.0
Cross-validated	Count								
Long Island		20	1	0	0	0	0	0	21
Little Cove and Soldier Point		0	23	0	0	0	0	0	23
Blackman's Point and Coconut Hall		0	2	20	0	0	1	0	23
Corbison Point and Dry Hill		0	0	0	20	0	1	1	22
Shirley Heights		0	0	0	0	7	0	0	7
St. Kitts		0	2	1	1	0	14	0	18
Puerto Rico		0	0	2	0	0	2	42	46
	%								
Long Island		95.2	4.8	0	0	0	0	0	100.0
Little Cove and Soldier Point		0	100.0	0	0	0	0	0	100.0
Blackman's Point and Coconut Hall		0	8.7	87.0	0	0	4.3	0	100.0
Corbison Point and Dry Hill		0	0	0	90.9	0	4.5	4.5	100.0
Shirley Heights		0	0	0	0	100.0	0	0	100.0
St. Kitts		0	11.1	5.6	5.6	0	77.8	0	100.0
Puerto Rico		0	0	4.3	0	0	4.3	91.3	100.0

Table 2.15. Assignment results of DA analysis. In total, 95.6% of original grouped cases is correctly classified and 91.3% of cross-validated grouped cases is correctly classified.

a variety based on similarities with actual source materials, a chert type. The first one is an artificial group constructed by the researcher, whereas the second one is a real (natural) group. Usually the first one will be narrowly defined, only incorporating chert pieces, that are very similar in colour, clast contents, grainsize, and texture, whereas the latter one may cover a broad variation of colours, grainsizes, and textures, depending on the variability of the source. To give an example of the difficulties that may be encountered, I found a specific dull light coloured chert variety and a more translucent brown one among the artefacts of the Saladoid site of Sorcé on Vieques. Initially using a sub-sample, I defined two varieties, thereby suggesting more or less that they originate from two sources. Studying more artefacts, however, I discovered that both varieties were occurring in a single artefact, meaning that they actually represent two sub-varieties of a single source. If these unknown varieties were encountered, I usually specified whether or not they exhibited similarity with one or more of the known source varieties. In this way, I had some direction in evaluating likely source origins, and more importantly, I could exclude a number of source localities a priori, facilitating the evaluation.

Only a few archaeological sites were chosen, from which artefacts were selected for chemical analysis. These include the ones that produced relatively large samples of flake tool related materials. Furthermore, I attempted to include a site from every of the four temporal phases distinguished for the Ceramic period, as well as sites that would cover the Long Island flint distribution (see Chapter 3). Table 2.16 lists the selected sites.

Having assigned the artefacts to known or new varieties, I chose one artefact from the Long Island variety in addition to one each from the most important other varieties for chemical analysis. The selection of the latter artefacts was optional. Selection did not occur randomly, but was guided by the following principles: (a) the mass of the artefact preferably

Site	Island	phase	N
Sorcé	Vieques	Early Ceramic A	6
Anse des Pères*	St. Martin	Early Ceramic B	6
Spring Bay 3*	Saba	Late Ceramic A	1
Kelbey's Ridge 2*	Saba	Late Ceramic B	1
Golden Rock	St. Eustatius	Early Ceramic B	4
Sugar Factory Pier	St. Kitts	Early Ceramic B	3
Trants	Montserrat	Early Ceramic A	6
Morel	Guadeloupe	Early Ceramic A	3
Anse à la Gourde	Guadeloupe	Early Ceramic B (early occupation phase)	1
		Late Ceramic A (middle occupation phase)	1

Table 2.16. Sites from which artefacts have been analysed using ICPAES. Artefacts from sites with * have been analysed during earlier research described in Knippenberg (1995, 1999a). N denotes the number of artefacts analysed for each site.

had to be heavier than 5 g, facilitating sample preparation for ICPAES[18]; (b) the sample had to be a true representative of the variety in question, that is, its macroscopic characteristics were shared with the majority of the artefacts assigned to that variety, and (c) the artefact preferably did not entail technologically or functionally important information, in other words shatter was preferred over flake cores and utilized flakes (flakes with use or intentional retouch).

2.6.2 Source assignment

The concentration values of the different elements for the artefacts are listed in Appendix C. The DA analysis of the artefacts was divided into two series. A separate analysis was performed for the artefacts grouped to the Long Island variety. The remaining artefacts were analysed using two different procedures. During the first analysis, a priori knowledge on macroscopic characteristics was not used, whereas during the second analysis specific sources were excluded based on a priori information.

Twelve samples classified as Long Island flint and originating from different habitation sites were selected for ICPAES analysis. These samples were all part of larger sets of Long Island artefacts excavated at each of the sites. The sample of Vieques had been part of a larger sample of only seven artefacts, whereas the sample from Trants had been part of a sample of more than 550 Long Island artefacts. Using DA, during which a distinction was made between Long Island, the other two primary Antigua Formation sources, the secondary Antigua Formation sources, the Central Plain bedded chert sources, the Basal Volcanic Suite source from Shirley Heights, the St. Kitts sources, and the Puerto Rico ones, resulted in group of 10 samples assigned to Long Island (85%), one sample (A-F-StEGR-01) assigned to the closely related primary Antigua Formation source group (Little Cove and Soldier Point), and one sample (A-F-VISO-01) assigned to the Shirley Heights source. Closer look at the first and second choice source assignments learned that the second source assignment for this Golden Rock sample (A-F-StEGR-01) was Long Island, and almost all but one of the second source assignments of the other artefacts were the LC-SP source group. The close similarity among the three primary Antigua Formation sources was further supported by the small difference in D^2 values between the first source and second source for most of the samples.

As Keckla (1980) noted, if the variance-covariance matrices for each group are not equal, this will likely result in wrong assignments in case of similar D^2 values for the first and second source assignment. Above, I stated that the variance-covariance matrix is not equal when all the sources are included, primarily owing to significant variation differences between the tuff cherts on one hand and on the limestone flints on the other. Considering the small difference in D^2 values between the Long Island assignment and the Little Cove-Soldier Point assignment, I performed another DA analysis, using only the Long Island source and the Little Cove-Soldier Point sources as groups. The variance-covariance matrix is equal in this analysis. Using only four elements both source groups were separated, in which a 100% correct assignment of the source samples was obtained with cross-validation.

The results showed that all the artefacts were assigned to Long Island in this case. Furthermore, the D^2 values were

18 If the artefact possessed much cortex, the mass had to be higher, depending on the amount of cortex.

much lower for the Long Island source than for the Little Cove-Soldier Point source group, strongly suggesting that at least these 11 samples all originated from Long Island, thereby supporting the macroscopic identification (table 2.17).

The Vieques sample (A-F-VISO-01), however, formed an anomaly. Its first source assignment was Shirley Heights, whereas its second source assignment was St. Kitts. In particular, the first source choice was not expected based on the distinct macroscopic appearance of the Shirley Heights material when compared the Long Island one. Inspection of the concentration values for this sample showed that they all fell within the range of Long Island values, except for Mn, which was significantly higher in the artefact sample. Based on the chemical similarity with Long Island, two additional DA analyses were performed: one in which only Long Island and Shirley Heights were included, and the other in which only Long Island and St. Kitts were included. Contrary to the first analysis, these two produced a Long Island assignment for the artefact, even if Mn was included. The chance that the artefact originated from Long Island became considerably higher when Mn was excluded from the analysis.[19]

In case of the source identification of the other samples several questions were at issue. First, a number of different source varieties were included, demanding a DA analysis that incorporated all the available sources. Secondly, a number of unknown varieties were also among the samples. This required a means by which it would be possible to ascribe the sample to an unknown source not included in this study. The attempt to find a method of overcoming the second problem revealed that the chemical data for the Caribbean cherts and flints do not properly lend themselves to this purpose. As I noted above, the high D^2 values for first choice source assignments for some of the source samples, in particular those from the Puerto Rican sources, pose difficulties in choosing specific cut-off values, as Luedtke (1979) recommended.

Therefore, other means were sought to see whether samples might be excluded from assignment to one of the sources in the study. An informative way is to evaluate the Al and K concentrations and especially the Al/K ratios. In some sources Al/K is very constant, making it possible to exclude source assignment with relatively good accuracy on the basis of this value alone. Where more variation is present in other sources, Al and K can be correlated with the majority of the other elements. Therefore, on the basis of a combination of Al and K with these correlated elements, certain samples can be excluded from assignment to these sources. This appears to be useful when samples contain very low Al and K values, which in some artefacts were below all values found for the sources.[20] Considering the high variation of Al and K in some of the sources, it seems likely that some rock pieces from such a source, not included in the present sample, actually contain such very low values.

A procedure, in which the different islands were first discriminated before samples were assigned to different sources produced the following results. All samples, except one, were either assigned to the Antigua or St. Kitts sources. The single artefact assigned to the Puerto Rico localities came from the Sorcé site (A-C-VISO-04), which is reasonable considering the fact that Sorcé is situated closest to these localities. However, despite this assignment to the Puerto Rico sources, the concentrations of the elements did not perfectly correspond with the concentrations from one of these sources. In particular, the low Al and K concentrations of the artefact are not present among the Puerto Rico localities. This means that the possibility of an unknown source origin cannot be excluded. Interestingly, the other chert artefacts from Sorcé do not originate from the Puerto Rico sources. This signifies that the southwestern Puerto Rican chert localities were not important in chert procurement on Vieques.

Among the 19 artefacts ascribed to either Antigua or St. Kitts, eventually three groups could be distinguished after assignment to the source level had occurred. For the first group of artefacts, the macroscopic identification corresponds with the chemical one, while in the case of the second group of artefacts macroscopic identification does not correspond with the chemical assignment. The third group included artefacts that were initially grouped as unknown varieties. Each group can be subdivided into samples for which the Mahalanobis distance does not exceed the maximum value found among the source samples themselves (low D^2), and samples for which it does (high D^2).

In particular, the last two groups present difficulties in deciding whether they should be assigned to the source based on DA analysis, or whether they should be assigned to an unknown source. On the basis of low Al and K concentrations, and low Al/K ratios, which are not represented among the sources, four samples are ascribed to unknown sources (StMAP-03 and StEGR-05; GUMO-02 and GUMO-03). The latter two samples from Morel are from the same variety of white chert, but are assigned to two different source localities. This assignment suggests that at least one source has been mistakenly chosen.

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19 Excluding Mn during the initial analysis produced a Long Island assignment for this source as well. However, this diminished the overall correct assignment rate of this analysis, as was shown by cross-validation.

20 The opposite, that is very high values above the ranges found for all sources, did not occur.

Sample number	Site	Source assignment	Comments
A-F-VISO-01	Sorcé	Long Island	-
A-F-StMAP-02	Anse des Pères	Long Island	-
A-F-StMAP-04	Anse des Pères	Long Island	-
A-F-StMAP-06	Anse des Pères	Long Island	-
A-F-SaSB3-01	Spring Bay 3	Long Island	-
A-F-SaKB2-01	Kelbey's Ridge 2	Long Island	-
A-F-StEGR-01	Golden Rock	Long Island	-
A-F-StEGR-02	Golden Rock	Long Island	-
A-F-STKSFP.a-01	Sugar Factory Pier	Long Island	-
A-F-MOTR-01	Trants	Long Island	-
A-F-GUMO-01	Morel	Long Island	-
A-F-GUAAG-01	Anse à la Gourde	Long Island	-
A-C-VISO-05	Sorcé	Soldier Point	-
A-C-STKSFP.a-02	Sugar Factory Pier	Soldier Point	-
A-C-STKSFP.a-03	Sugar Factory Pier	Coconut Hall	-
A-F-GUAAG-02	Anse à la Gourde	Coconut Hall	-
A-C-MOTR-06	Trants	Blackman's Point	-
A-C-MOTR-02	Trants	Dry Hill	-
A-C-VISO-03	Sorcé	St. Kitts?	low D^2
A-F-StMAP-01	Anse des Pères	St. Kitts?	low D^2
A-C-VISO-06	Sorcé	Coconut Hall	low D^2
A-F-StMAP-05	Anse des Pères	primary Antigua Flint	low D^2
A-C-MOTR-03	Trants	Shirley Heights?	low D^2
A-C-VISO-04	Sorcé	unknown	low Al and K
A-F-StMAP-03	Anse des Pères	unknown	low Al/K
A-C-StEGR-05	Golden Rock	unknown	low Al/K
A-C-GUMO-02	Morel	unknown	low Al/K
A-C-GUMO-03	Morel	unknown	low Al/K
A-C-VISO-02	Sorcé	unknown	high D^2
A-C-StEGR-04	Golden Rock	unknown	high D^2
A-C-MOTR-04	Trants	unknown	high D^2
A-C-MOTR-05	Trants	unknown	high D^2

Table 2.17. Source assignment for chert artefacts found at different habitation sites.

In relation to the remaining samples, those with Mahalanobis distances not exceeding the largest Mahalanobis distance of the source samples for that particular source are ascribed to the source provided by the DA-analysis. In the other cases, samples are from unknown sources.

After these assignments, the group of identified sources include Coconut Hall, Blackman's Point, Soldier Point, Dry Hill, Shirley Heights, and St. Kitts (tables 2.17-18). In particular, the identification of the first four sources should be considered certain, whereas some doubts pertain to the latter two.

Site	Island	Identified sources
Sorcè	Vieques	Long Island, Soldier Point, Coconut Hall, St. Kitts (?), unknown
Anse des Pères	St. Martin	Long Island, primary Antigua flint sources, St. Kitts (?), unknown
Spring Bay 3	Saba	Long Island
Kelbey's Ridge 2	Saba	Long Island
Golden Rock	St. Eustatius	Long Island, unknown
Sugar Factory Pier	St. Kitts	Long Island, Soldier Point, Coconut Hall
Trants	Montserrat	Long Island, Blackman's Point, Dry Hill, Shirley Heights (?), unknown
Morel	Guadeloupe	Long Island, unknown
Anse à la Gourde	Guadeloupe	Long Island, Coconut Hall

Table 2.18. Identified source localities for flint and chert artefacts by settlement site.

2.7 Conclusion

In this chapter I have reviewed a number of potential chert sources within the northern Lesser Antilles and Puerto Rico. It appears that chert and flint varieties relevant to this study have restricted natural occurrences, which basically can found on three islands: Antigua, St. Kitts, and Puerto Rico. The small geographical extent and their rare presence offered great opportunities for a regional research aiming at raw material distribution among the different islands of the Lesser Antilles. Therefore, this research has attempted to find a means to distinguish the different chert and flint occurrences on the island, facilitating the determination of provenance for the individual artefacts.

The determination of trace-element concentrations using ICPAES provides objective criteria for reaching this goal. From careful comparison of data between the sources, it is evident that inter-source variation is primarily a result of host-rock variability and to a lesser degree dependent on variation in time and space. Differences can be related to different terrigeneous and marine authigenic mineral presence in the chert rocks. Flint outcropping in different areas but formed in the same limestone will contain similar mineral inputs, and only the concentration values may be variable. Chert in tuffs, however, differ in mineral inputs. Furthermore, it is clear that cherts in tuff display large intra-source variability owing to diverse origins for the silica. Weathering also has a significant effect on trace-element composition. Generally, the final effect is disadvantageous for source discrimination, as intra-source variability increases. Under specific circumstances, however, as is shown by the Blackman's Point material, it can have a differentiating effect.

Correct artefact assignment to the level of source locations proves to be difficult due to significant overlap between sources from similar geological origins. Discriminating geologically related source groups, or distinguishing the three different islands, produces better results. Another problem with regard to the artefact assignment, is related to the evaluation on the use of sources not included in this study. It proves to be very difficult to determine whether unknown varieties originate from one of the sources included in this study or from another unknown source. Generally, this is further complicated by the rare occurrence of such varieties among archaeological samples within the study area. To partly overcome this problem, it is recommended that several samples be taken from such an unknown archaeological variety. This will provide a trace-element pattern that facilitates comparison with known sources.

Other recommendations for future research, should improve the correct assignment rates. These include additional sample taking at the Dry Hill and Corbison Point localities, for example. By more thoroughly analysing different beds, researchers should be able to define sub-sources within these localities, significantly diminishing overall overlap with other source localities and consequently improving assignment results. Also, the Shirley Heights source and other localities within the Central Plain and Basal Volcanic Suite regions of Antigua require additional surveying and sample taking. Among the artefact samples still unknown varieties are encountered and based on the large variety of cherts, that turn up in excavations on Antigua, these areas are the most likely ones where additional sources will be found.

In relation to the St. Kitts sources, future research should attempt to determine the age of these flints by analysing Dinoflagellates. This will provide data by which it will be possible to see if these flints were, in fact, formed on St. Kitts, or whether they represent artificial scatters dropped during Historic times (see Appendix A for a discussion on the origin of St. Kitts flints). Additional research among Puerto Rican chert sources should focus on the geological origin of the cherts and more attention should be paid to rock weathering by taking samples from the surrounding soils.

2.8 Other raw materials: calci-rudite and greenstone

2.8.1 A multicoloured conglomerate: calci-rudite zemi-stone from St. Martin

During the study of different collections of archaeological lithic artefacts (see Chapter 5), a very characteristic raw material was repeatedly present. Others before me have occasionally reported finding it at various sites within the northern Lesser Antilles (Crock 2000; Crock & Petersen 1999; Haviser 1987,1993, 1999; Hoffman 1963, 81, plates V.B, VI.B; see also Hoffman 1970; Hoogland 1996; Versteeg 1999). The indigenous populations of the northwestern Lesser Antilles used this material to manufacture zemi three-pointer stones, important objects with religious and spiritual significance (figure 2.27)(McGinnis 1997; Pané 1999; Siegel 1997).

The lithic material in question can be described as a mixture of round and angular particles (clasts) cemented by a fine-grained limestone matrix (figures 2.27-29). Among the clasts a distinction can be made between round to oval white (N8) to light grey (N7) and occasional pale red (10R 6/2) grains, and dark (black (N2.5) to greenish black 5G 2.5/1) rounded

Figure 2.27. Two calci-rudite zemi three pointer stones found at the Anse à la Gourde site, Guadeloupe. See figure 5.32 for the drawing of both zemis. (Photos Ben Grishaaver)

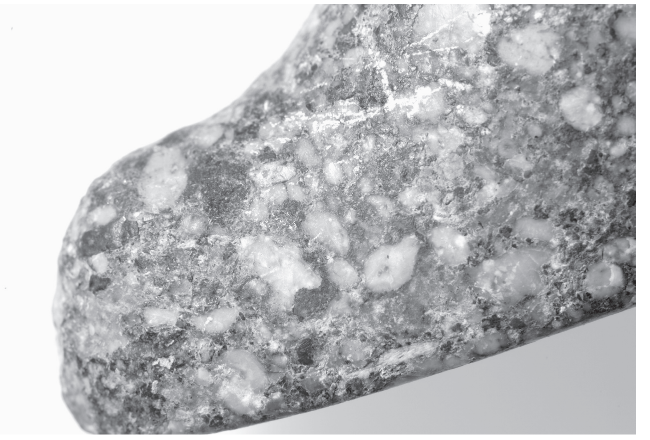
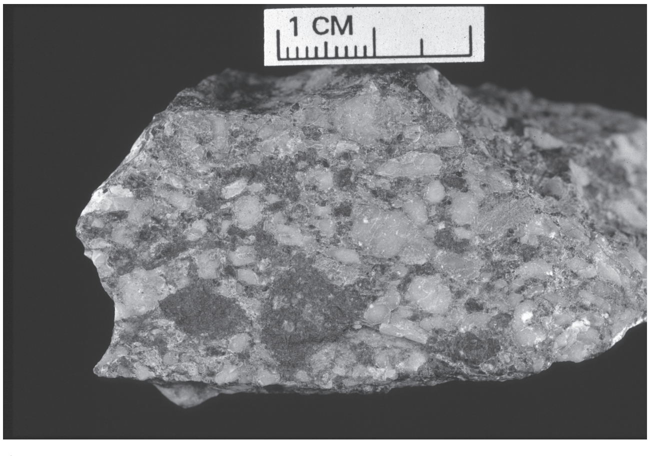


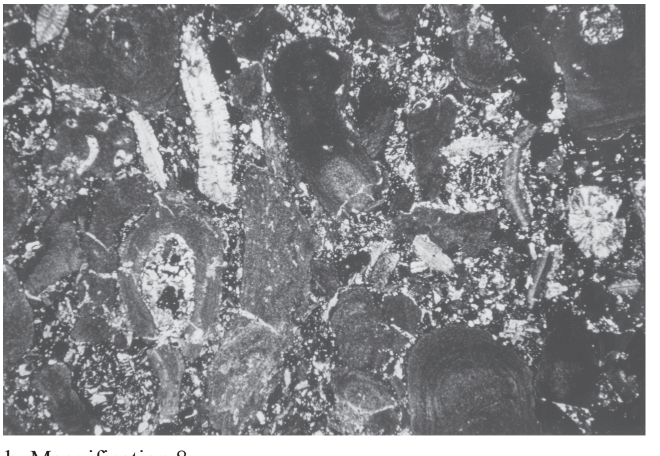
Figure 2.28. Close-up of the conglomeratic texture of both calci-rudite zemi three pointer stones depicted in figure 2.27. (Photo Ben Grishaaver)

to angular particles (Van Tooren 1993). This rock has a very distinctive overall appearance, making it easily recognizable. However, variation can occur in the size of the grains and particles. The distinct combination of light and dark clasts and low variation among different artefacts suggest that this material originates from one and the same source location.

To date, a single artefact of this rock, found at the Early Ceramic Age Hope Estate site, has been studied petrographically using standard microscopic techniques (Haviser 1993, 1999; Van Tooren & Haviser 1999). Van Tooren, working in the Laboratory of Engineering Geology at Delft University of Technology, has called the rock, calci-rudite, a conglomerate, which should be classified as a packstone following the classification scheme for sedimentary rock by Dunham (1962).[21] Within the rock, she identified the light coloured grey pebbles, making up 70% of the total sample as bioclasts (fossil fragments), including in diminishing order the following genera: red algae, *Discocyclinae*, *Lepidocyclinae*, Nummulites, as well as some unidentifiable fossils (figure 2.29). The dark coloured, grey pebbles are lithoclasts (rock fragments and detrital minerals), making up 25% of the total. Identified fragments include andesite fragments, glass,



a



b. Magnification 8x

Figure 2.29. Normal photo and thin-section photo of the calci-rudite sample analyzed by van Tooren (taken from van Tooren and Haviser 1999, 259 photos 6 and 7).

[21] Based on the granular texture of the rock, it has earlier been called porphyrite or porphyry by others (Crock 2000; Haviser 1987). This name is misleading since it would place it among igneous rocks. Although igneous particles are present within the rock, it should be classified as a sedimentary rock based on its formation.

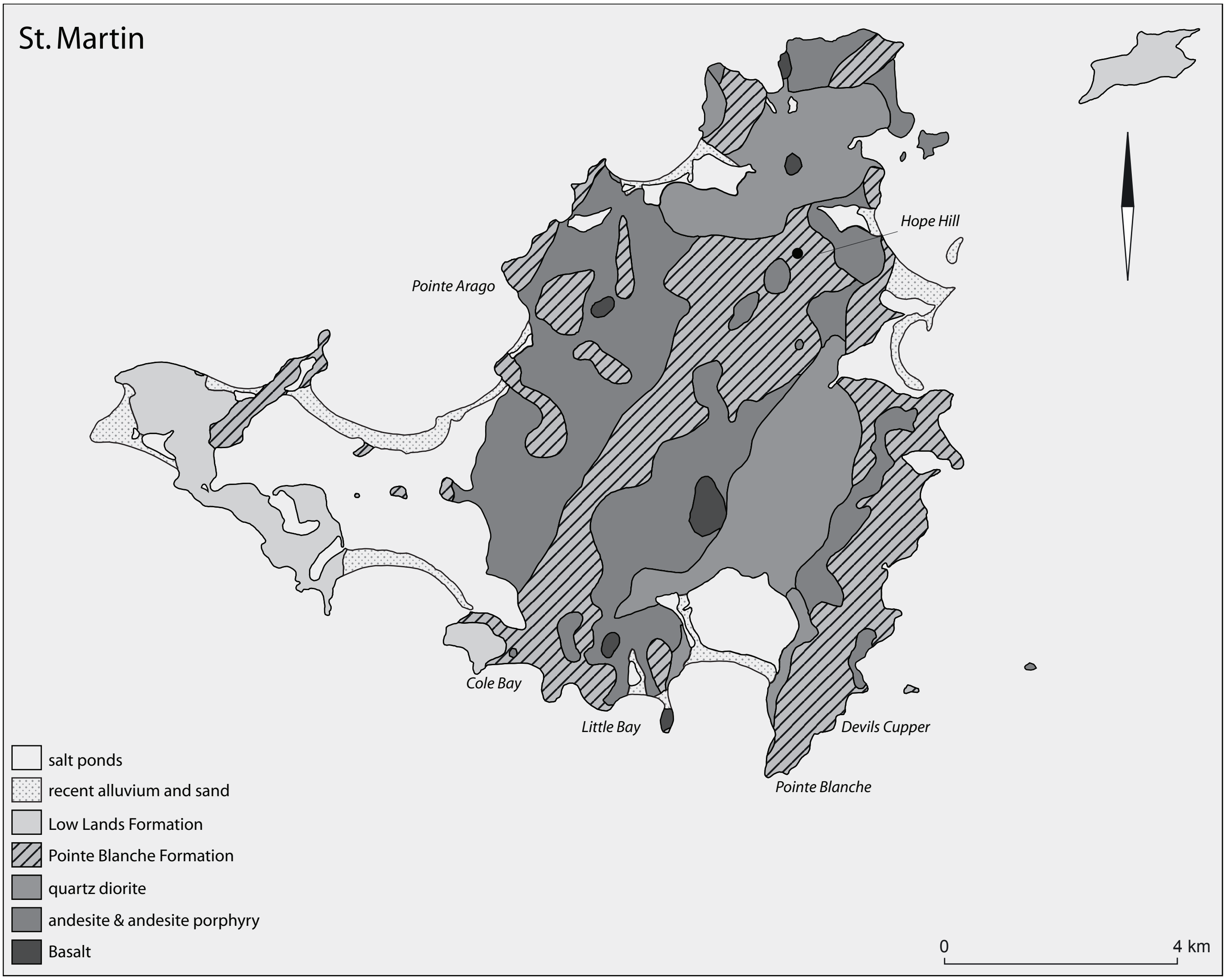


Figure 2.30. Geological map of St. Martin showing the regions where the Pointe Blanche Formation is the underlying rock formation (map based on Christman 1953). Indicated are the calci-rudite source at Pointe Arago and some other significant Pointe Blanche Formation outcrops.

hornblende and plagioclase minerals. The cement, 5% of the total, consists of micrite (fine-grained calcite), sparite, and iron hydroxides (Van Tooren 1993, 3-4). Based on the occurrence of *Discocyclinae* and *Lepidocyclinae* sp., she dated the rock to the Upper Eocene and placed the possible source of this rock on Jamaica, where Upper Eocene sedimentary formations occur (Van Tooren 1993, 4).[22]

Haviser later pointed out that Upper Eocene sedimentary occurrences are present on St. Martin and assumed the material to be local. A following report by Stouvenot supported this notion. He identified its source at Pointe Arago, a rock cliff between Baie de la Potence and Anse des Pères (figure 2.30) (Stouvenot 1999, personal communication 2001). Sections there reveal outcrops of sedimentary depositions belonging to the Pointe Blanche Formation, which is dated between at least Middle Eocene to Upper Eocene (Bonneton & Vila 1983). Bonneton and Vila have divided the Pointe Blanche Formation into three sequences. The middle sequence, which can be characterised as volcanic-sedimentary in nature in which andesitic rocks dominate ("série volcano-sédimentaire à dominante andésitique" (Bonneton & Vila 1983, 868)), is found at Pointe

[22] She based this observation on an old overview of Caribbean geology written by a German geologist, Weyl (1966).

Arago, and has hereafter been named the Pointe Arago Formation by the authors. In addition to nicely stratified pyroclastics, inter-bedded with tuffs and siliceous beds, large deposits of conglomerates and micro-conglomerates occur. These latter can be characterised by cementation of lava debris (lithoclasts) with fossils (bioclasts), such as Mélobisiees, Enchinoderms, Lamellibranches, and Nummulites. Some rare deposits contain *Lepidoclyna* sp. and *Discocyclina* sp. (Bonneton & Vila 1983, 884), the species that occur in the calci-rudite studied by Van Tooren.

Based on the similarities in composition between the analysed artefact and the description of the conglomerate rocks at Pointe Arago, both contain lithoclasts, predominantly in andesite form, and the same fossil species: Discocyclinae, Lepidocyclinae, and Nummulites, the source of this rock material must be assigned to this area along the western coast of St. Martin.[23] This locality correlates well with the archaeological data (see Chapter 5), which show that sites on Anguilla, the neighbouring island to the western side of St. Martin, produced large quantities of this material. Unfortunately, evidence of pre-Columbian exploitation at Pointe Arago locality itself has yet to be demonstrated.

2.8.2 A grey-green mudstone: greenstone from St. Martin

Despite the fact that I have called this material "greenstone", the rock discussed here often does not look at all like a greenstone within the archaeological record. In many cases it is white, sometimes very corroded and chalky, and it easily loses pieces of its outer surface-layer (figure 2.31). The colour of this corroded surface varies from true white to very pale brown (10YR 7/3-7/4) to light grey (10YR 7/1) to light brownish grey (10YR 6/2), probably to some degree depending on the influence of the surrounding soil on the different archaeological sites. The crumbling outer surface likely suggests that chemical weathering has altered the rock. This is made clear by some specimens, which still possess remnants of their original texture, often found in the form of thin layers following natural bedding within the rock itself (figure 2.32). The original texture can be described as dull, homogenous, and fine-grained, resembling chert and flint in its flaking characteristics. Its colour varies from light greenish grey (5GY 7/1, 5G 7/1, 10GY 7/1, 10BG 7/1) to greenish grey (5G 6/1-5/1, 5BG 6/1, 10Y 5/1). Colour variations can occur within single specimens, which follow the internal layering of the rock.

Many archaeologists working on St. Martin and its surrounding islands have reported finding this rock during their excavations. The earliest account goes back to the work of Josselin de Jong at Golden Rock on St. Eustatius, where he discovered numerous axe and "chisel" fragments, with a characteristic "crust of earth", or "loam-like earth" (Josselin de Jong 1947, 42, PlateXII.30,37-40,48, PlateXIV.1-4,15-16). Many years later Haviser (1987) mentioned the finding of a "chalky grey-green chert" celt production at Cupecoy Bay on St. Martin, followed by similar discoveries at Hope Estate (Haviser 1988, 1991, 1999). Watters, performing small-scale excavations within Fountain Cavern on Anguilla in 1986, found 5 core artefacts, of which at least one was a celt bit, made of similar material as the Hope Estate and Cupecoy Bay material reported by Haviser (Watters 1991, 279-282, 291). Recently, John Crock, University of Pittsburgh, has identified large quantities of artefacts relating to an axe production at numerous sites on Anguilla (Crock 1999, 2000; Crock & Petersen 1999).

Classification of the rock type in question has been difficult due to the material's weathered nature. This uncertainty is well reflected by the number of names it has previously been given. Initially, Haviser called it grey-green chalky chert in his Cupecoy Bay report (Haviser 1987). He later changed its name to radiolarian limestone[24], after "casual identification" by B. Fouke of Stony Brook University of New York (Haviser 1993, 2; Haviser 1999, 189). Following the 1993 excavations at Hope Estate, Haviser sent an archaeological sample specimen of this rock (6-C-6) to M. Van Tooren for petrographic analysis, in addition to a calci-rudite artefact, as discussed above.

Van Tooren distinguished two different parts in the specimen from Haviser, a light red rock and grey-green rock. She identified the former under the microscope as being of biogenic origin. It mainly consists of a micrite (fine-grained calcite) matrix, in which many canals are present, probably the result of some organism. The grey-green part of the rock was identified as an altered tephrite, built-up by fine crystalline minerals, which include plagioclase, leucite, chlorite, hornblende, titanite, calcite, and unidentified opaque minerals. Based on these results, Haviser started to make a distinction between tephrite A and tephrite B in his description of the lithic artefacts from Hope Estate, the A-type being the limestone rock and the B-type being the altered volcanic rock, or the true tephrite (Haviser 1993, 1999). Although van Tooren does not mention

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[23] In addition to Pointe Arago, another Middle Eocene sequence is reported on St. Martin at Red Pond Bay, where conglomerates occur. These conglomerates are coarser in nature, however, and the occurrence of two fossil species (*Lepidocyclina* and *Discocyclina*) is not noted.

[24] French reports on later Hope Estate excavations use the related term "radiolarite" for this material (Chauviere 1998).

Figure 2.31. Corroded greenstone artefact from the Early Ceramic Age Anse des Pères site, St. Martin, showing extensive weathering (scale 1:1). (Photo Jan Pauptit)

it, it is of interest to specify that the "red" limestone part corrodes into the typical chalky rock, while the grey-green part does not.[25]

Following my earlier Master thesis research related to the lithic artefacts from Anse des Pères, a late Saladoid site on the west coast of St. Martin, I performed a re-analysis of a series of thin-section samples for artefacts from this site with the help of Tony Senior and Gerrit Klaver.[26] These samples included five weathered and three partly weathered examples of this grey-green material, a non-weathered dark green sample, as well as four rock samples from a geological context on St. Martin. Based on the analysis of the artefacts, we concluded that the weathered grey-green rock should be classified as a mudstone, following Dunham (1962), as it is essentially a sedimentary rock, rather than an igneous one. The non-weathered dark green piece appeared to be a totally different type of rock, which already was clear to some extent when comparing it macroscopically. This latter sample consists of garnet and quartz, and can be classified as a metamorphic rock.[27]

Closely comparing the corroded and partly corroded grey-green samples showed that they are similar, although some contain features not shared by others. More specifically, they are sedimentary rocks with a volcanoclastic component, suggesting sedimentation occurred during active volcanic periods. The matrix of this rock consists of very fine-grained,

25 This macroscopic identification of corrosion was based on the original colour pictures, which were taken of the rock sample. A black and white duplicate has been published in Van Tooren and Haviser (1999, 257, Photo 1).

26 During my PhD-work, the samples from my Master Thesis work were re-analysed by Tony Senior (Faculty of Earth Sciences, University of Utrecht) and Gerrit Klaver (Institute of Applied GeoScience (TNO-NITG, Utrecht).

27 Careful reading of geological works on St. Martin demonstrates that this sample may have been local to the island, as garnet is reported in the metamorphosed contact zone between the plutonic rock and the Pointe Blanche formation tuffs (Molengraaff 1931; Staargaard 1952).

Figure 2.32. Uncorroded greenstone rock sample from the Hope Hill contemporaneous quarry site (a) and partially corroded greenstone axe from the Late Ceramic Age Anse à la Gourde occupation phase (b) and close-up showing a thin uncorroded band (c).(Photos Ben Grishaaver)

partly re-crystallised material, which could not be identified on the basis of the thin-section study (figure 2.33). Chemical analyses of a sub-sample of four archaeological samples, using ICPAES and earlier microprobe data (see Knippenberg 1995), indicates that the amount of Ca is very high, suggesting that it mainly consists of very fine carbonate mud. High Al, K, and Na values suggest that there is likely a tuff and/or clay component present as well. These fine materials were deposited in a marine environment, as indicated by the presence of rare fossils, such as foraminifers and radiolarians. In addition to the possible tuff, rare occurrences of larger and identifiable igneous rock fragments, in the form of probable wind-blown plagioclase minerals, provide additional evidence for volcanic influences during deposition (see figure 2.33).

The high concentrations of Ca must be associated with the characteristic surface corrosion of this rock, which makes the material so easily recognizable. It is probably a process where the less stable components dissolve and the carbonate remains.

Notwithstanding this classification, there remains a discrepancy between Van Tooren's identification of this rock as tephrite and our petrological results. If both data are compared, the following points emerge:

1) Both the corroded part of the specimen studied by Van Tooren and my corroded samples contain significant amounts of carbonate in the form of micrite, suggesting a marine origin.

2) The non-corroded part of Van Tooren's sample is identified as an altered tephrite, but none of my corroded samples can be classified as such. However, considering the variable nature of its origin within the Pointe Blanche Formation (see below), where sedimentary rocks occur inter-bedded with tuffs and igneous rock, the existence of two different rock-types in one piece likely represents the interface of two beds, in which the non-corroded part belongs to a layer consisting of igneous rock, whereas the corroded part belongs to a sediment overlying it.

This means that only corroded specimens contain carbonate in the form of micrite and that the development of the chalky surface is associated with this content. This also means that naming this corroded stone as tephrite A, as Haviser does in his Hope Estate lithics report (Haviser 1993, 1999; Van Tooren & Haviser 1999), is erroneous because it is primarily a marine sediment and not an igneous rock. The name tephrite should be reserved only for non-weathered artefacts corresponding with the proper mineral composition.[28] Non-corroded artefacts, however, only form a small part of the archaeological samples[29], probably owing to its inferior flaking characteristics. This suggests that the Amerindians specifically preferred and used the calcareous beds within the Pointe Blanche formation, and not the igneous ones.

Contrary to what Van Tooren and Haviser (1999) claim after their analysis of a single sample, namely that the material is well defined, I conclude that although they correctly described this sample, Haviser unhappily chose a complex specimen, which cannot be considered as representative for the majority of the archaeological materials. This led to the use of an incorrect name, tephrite, for the rock category as a whole.

With regard to the source of this material, the Middle to Late Eocene Pointe Blanche Formation on St. Martin is considered the most likely origin. This geological unit outcrops at many places on St. Martin, with notable locations at Little Bay, Pointe Blanche, Red Pond, Devils Cupper, and Cole Bay (see figure 2.30) (Bonneton & Vila 1983; Christman 1953). Generally, this formation consists of a bedded sequence of fine-grained re-crystallised green and white tuffs. In some places tuffs are calcareous or cherty in nature, or lack re-crystallisation. True cherts are reported at Devils Cupper and north of Marigot. Coarser grained tuffs occur along the coast between Oyster Pond and Geneve Bay (Christman 1953). At some places, andesite and dacite dykes and sills inter-bed the tuffs, such as at Pointe Arago (Bonneton & Vila 1983).

Considering this, Haviser and I took geological samples for comparison from a present day quarry site at Hope Hill, where a significant part of the Pointe Blanche Formation is exposed, providing easy access and good stratigraphic visibility (see figure 2.30). From a rock section in which thin (dark) green and grey-green beds of cherty material are present, four samples were taken from four different beds (figure 2.34). Within this sequence of beds, there are beds with rock material that exhibits good conchoidal flaking characteristics and there are other beds where the material is unsuitable for flaking, as it easily falls apart. The good quality material is usually (light) grey-green in colour and resembles a dull chert (see figure 2.33), while the poor quality material usually can be found among the (dark) green materials, which are coarser grained.

Two out of the four geological samples (the light grey-green ones) display similarity with the archaeological specimen under the microscope, although close similarity is not shared with all archaeological samples (see figure 2.33).

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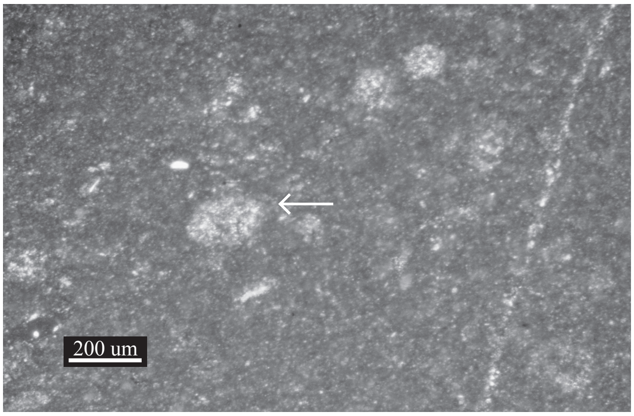
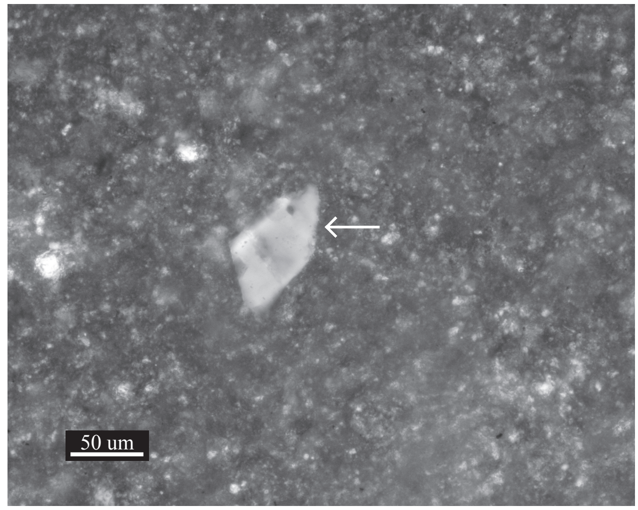
[28] The highly variable build-up of the Pointe Blanche Formation, including the occurrence of different beds of igneous rock, suggests that other tuff or igneous rock varieties than the identified tephrite may be present among non-corroded specimens. Therefore, in case of the significant use of non-corroded rock, such possible variation should be studied by analysing several samples.

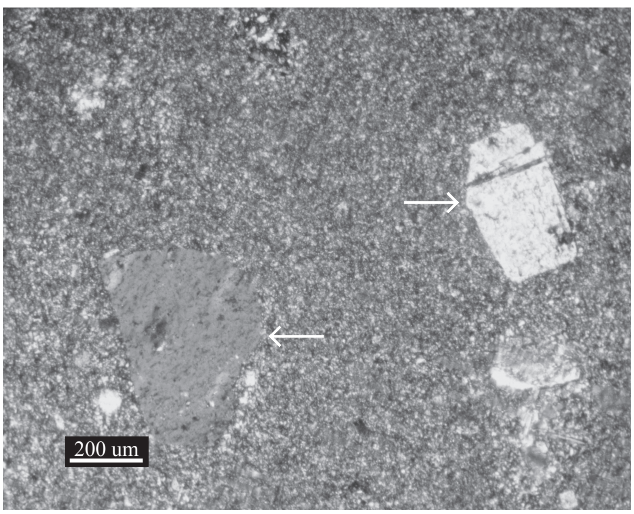
[29] Within all assemblages that I studied, the weathered artefacts make up the large majority, often more than 90% of this category.



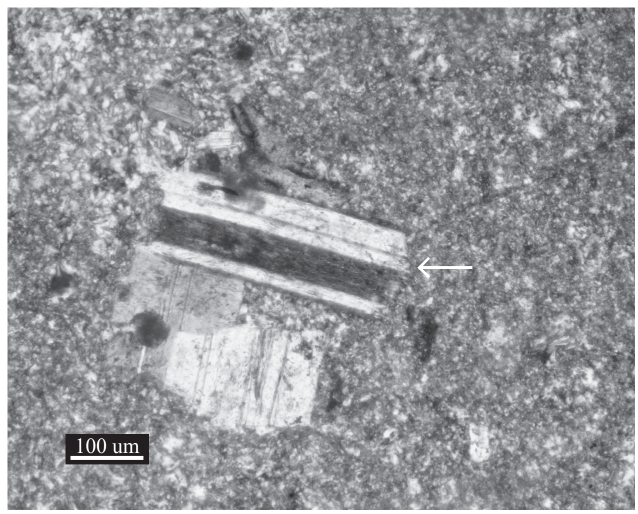
a. Hope Hill greenstone, geological sample StMHH-02 (CP).



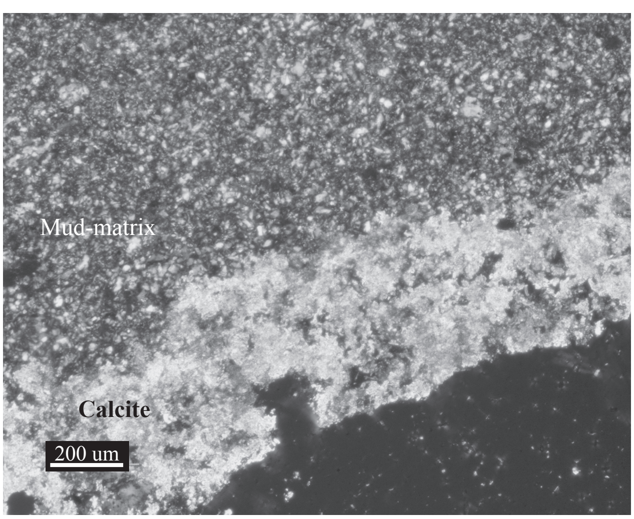
b. Hope Hill greenstone, geological sample StMHH-02 (CP).



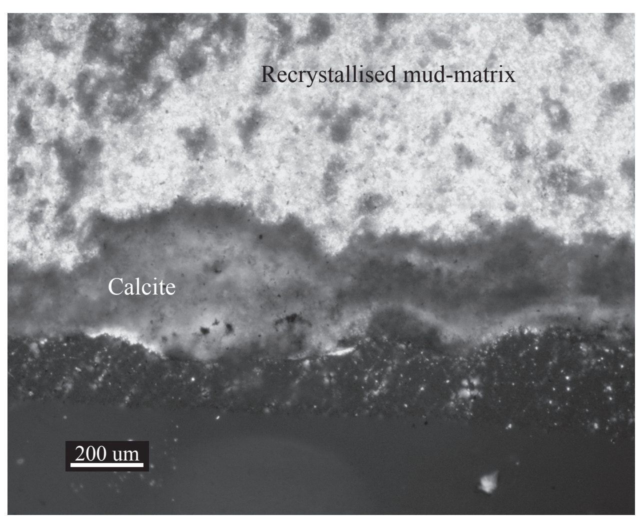
c. Anse des Peres greenstone, artefact sample StMAP-01 (CP).



d. Anse des Peres greenstone, artefact sample StMAP-01 (CP).



e. Anse des Peres greenstone, artefact sample StMAP-08 (CP).



f. Anse des Peres greenstone, artefact sample StMAP-08 (CP).

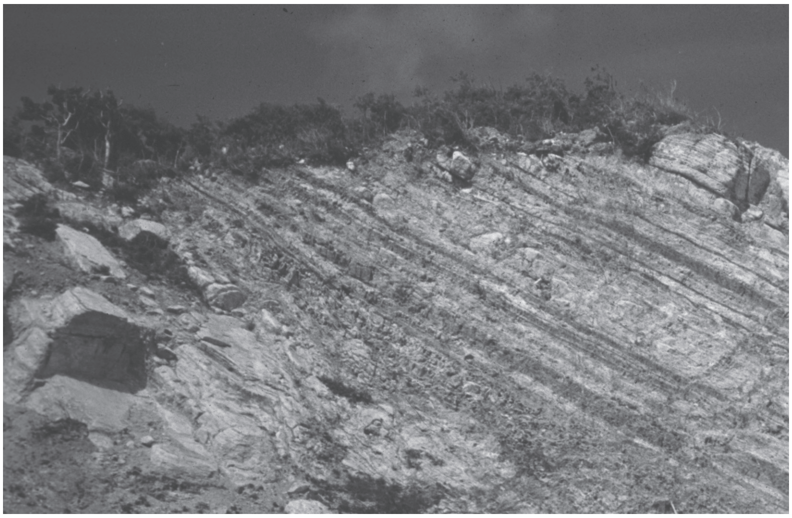


Figure 2.34. Rock section at the contemporary Hope Hill stone quarry exposing a significant portion of the bedded sequence of the Pointe Blanche Formation.

Both geological samples have very fine re-crystallised matrices, in which fossils and volcanic fragments (plagioclase and quartz) can be identified. In one of the samples, the matrix probably contains tuff as well.

The other two samples are of a different nature. One is a tuff, consisting of very fine homogenous distributed material. The other is a true igneous rock of the hypabyssal type, with clino-pyroxene and plagioclase phenocrysts, which had been partially replaced by amphibole and kali-feldspar, respectively. This variation in rock-types clearly corresponds with descriptions of the Pointe Blanche Formation provided by the different geological reports, in which igneous rock, tuffs, and calcareous sediments are distinguished (Bonneton & Vidal 1983; Christman 1953).

The two samples displaying similarity with the archaeological samples were submitted for chemical analysis, using ICPAES. These data were compared with the data from four chemically analysed archaeological samples (table 2.19). This comparison shows that the geological samples differ from the archaeological ones, despite their similarity under the microscope. Both groups of samples contain high concentrations of Ca, suggesting carbonate formed a major constituent of the rock. The archaeological samples, however, contain two to three times more Ca than the geological ones. The geological samples are richer in Al, K, Na, Fe, Ti, and Mg, suggesting that the igneous-tuff-clay fraction is more significantly represented. This minimally indicates that the archaeological samples excavated at Anse des Pères did not originate within the two analysed beds at Hope Hill. Considering that the Hope Hill samples were obtained from a contemporary stone quarry, it was not expected that Hope Hill was necessarily the source or the archaeological specimen. Given the similar nature of both groups, and the common occurrence of the Point Blanche Formation at many outcrops, it is likely that the Anse des Pères inhabitants obtained this material elsewhere on St. Martin.

Another striking feature of the comparison between the geological and archaeological samples needs to be mentioned. Variation among most of the elements in the two geological samples (in particular Al, K and Na) is more significant than within the four archaeological samples. Since both geological samples originated in two different beds (layers) at Hope Hill, the relatively closer similarity between the archaeological samples may suggest that they originated within a single bed. If it is true that inter-bed variation is significant and intra-bed variation is not, this may guide the search for possible prehistorically quarried outcrops on St. Martin. For example, it would suggest that the outcrops along St. Martin's southern coast, e.g., Little Bay, were not likely exploited by the Anse des Pères inhabitants, as rock sections here expose numerous beds of flakable grey-green material. A more inland outcrop, where only limited portions of the Pointe Blanche Formation come to the surface, may be a more likely quarry locality.

However, this low chemical variability among the grey-green rock only accounts for this small sample from the Anse des Pères site. A more extensive sampling program might produce different results. Furthermore, the study of other

Figure 2.33 (opposite page). Thin-section photos of St. Martin greenstone in crossed polars (CP). a. Arrow points to radiolarian fossil floating in a fine matrix; b. Arrow points to small plagioclase fragment floating in a fine matrix; c and d. Arrows point to larger plagioclase fragments floating in a fine matrix; e and f. Corroded outer surface in thin-section clearly showing the corroded outer surface consists of calcite.

Sample number	Al	K	Na	Ti	Fe	Mg	Ca	Ba
geological samples								
BC-StMHH-01.1av	46604	8878.0	14208.7	1810.6	37322	16942	114160	578.91
BC-StMHH-02	27221	29251.9	3380.4	966.4	13836	11708	131089	1061.12
artefact samples								
A-BC-StMAP-08	18137	536.9	525.6	810.0	12355	5063	331073	21.73
A-BC-StMAP-04.1av	16933	1106.5	2518.3	851.5	25834	8508	290204	4.80
A-BC-StMAP-01	14222	281.8	1224.6	629.1	8937	4458	319612	-
A-BC-StMAP-09	13306	2017.8	2240.0	632.5	11950	5545	288552	174.94

Table 2.19. Trace-element concentration values (in mg/kg (ppm)) within St. Martin greenstone geological (Hope Hill) and artefact (Anse des Pères) samples. Suffix “-av” denote average values from multiple analyses.

grey-green axe production sites on St. Martin and surrounding islands (see Chapters 5 and 6) may well yield different results as well, if these axe producers came from different directions and visited different outcrops on St. Martin.

2.8.3 Concluding remarks

Petrographic analysis of two frequent rock types among archaeological samples from pre-Columbian sites within the northern Lesser Antilles, demonstrated that both materials originate on St. Martin. They are easily recognized due to specific features, that are solely related to them. The first variety, used for making three-pointer zemis, is a conglomeratic packstone, named calci-rudite, and it displays a very characteristic mixture of dark igneous rock clasts and light coloured fossils. The other, used for making axes, is a fine-grained grey-green re-crystallised mudstone, named (St. Martin) greenstone hereafter. The St. Martin greenstone is easily recognized as a result of its susceptibility to weathering which turns it into crumbly and chalky on its exterior.

The natural occurrences of both rock types on St. Martin are variable. Calci-rudite has been solely identified at Pointe Arago, a rock cliff along the west coast of St. Martin. Greenstone, however, has a wider distribution on the island, as it is generally associated with the Pointe Blanche Formation, which covers an extensive part of St. Martin’s surface. Its common presence and the fact that greenstone quarry sites have not been identified, make it impossible to pinpoint just where pre-Columbian people obtained this material. In relation to the calci-rudite packstone, data on its exploitation activities remain limited to one geographical location only, since related artefact scatters have not been reported on St. Martin.