Instrumental Neutron Activation Analysis of Onondaga Chert in the Niagara Frontier

Hugh W. Jarvis

A systematic and intensive sampling of a series of Onondaga chert outcrops along the Onondaga Escarpment in western New York State provides preliminary data for chemical characterization using instrumental neutron activation analysis (INAA). Concentrations of minor and trace elements generally increase eastward through the study area, providing a basis for more extensive analysis. Especially strong are the eastward elevations of bromine, chlorine, and sodium. Samples of artifacts from three western New York sites corroborate the geological data, although sodium leaching is in evidence. Discriminant analysis shows strong separation between outcrops, providing hope for future characterization.

Introduction

This paper discusses the chemical characterization of Onondaga chert for artifact sourcing. Data were collected through a systematic sampling strategy and analyzed by means of instrumental neutron activation analysis (INAA). Although artifacts of Onondaga chert dominate the prehistoric lithic assemblages of New York State, as well as being common in neighbouring states and provinces, no headway has yet been made at tracing the sources of this raw material. This study was in-tended to establish the feasibility of conducting large scale fingerprinting of this important prehistoric resource by using a more intensive approach and a larger data base than have ever been used before.

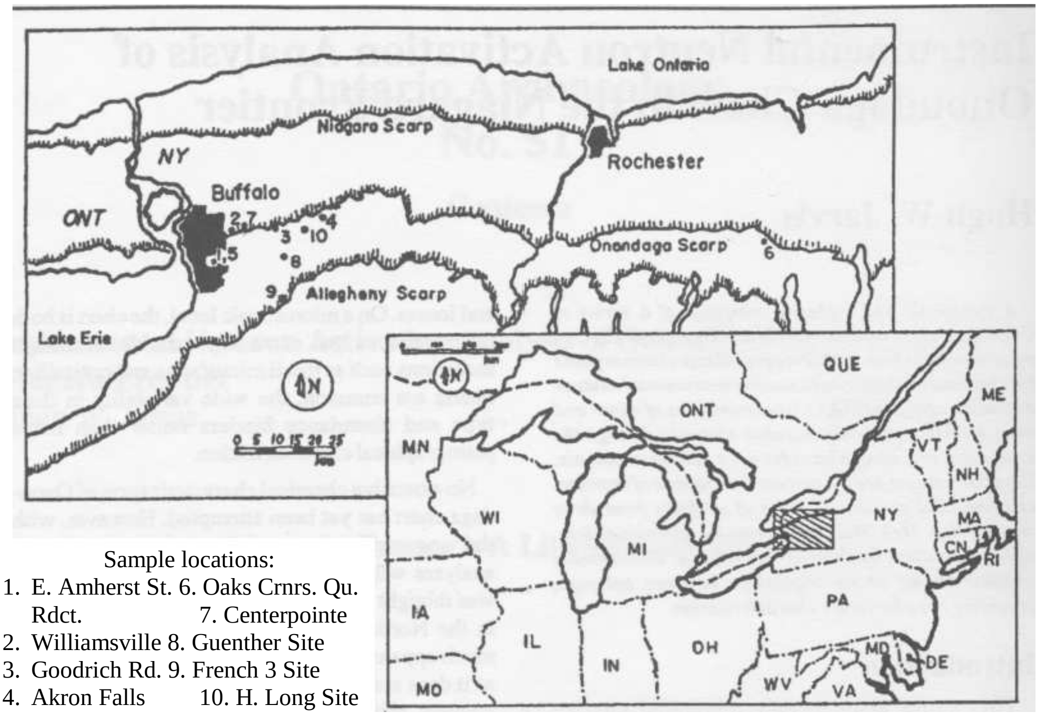
Although Onondaga chert has been the subject of various sourcing studies, the nature of the resource itself has hindered their success. Unlike some North American raw materials, for which there are but a few easily isolated point sources, exposures of the Onondaga chert occur in parts of southwestern Ontario, regularly across New York State, and also in northern Pennsylvania. This abundance would not be a problem if it were not for the chert's physical characteristics: it is macroscopically homogeneous, which prevents easy visual discrimination. While there can be small differences in colour between samples from opposite ends of New York State, there can be just as much variation between strata, and even across individual nodules and lenses. On a microscopic level, the chert is both heterogeneous and extremely variable. Although inclusions such as fossil microfauna and crystalline quartz are common, the wide variability in their type and abundance hinders rather than helps petrographical characterization.

No extensive chemical characterization of Onondaga chert has yet been attempted. However, with the accomplishments made by trace element analyses worldwide, in difficult sourcing cases, it was thought appropriate to try such a method here in the Northeast. Since this chert type shows as much apparent variation inside individual outcrops as it does across the whole formation, a systematic strategy using data gathered intensively from a series of locations was designed. As Luedtke (1978, 1979, 1987a, personal communication) has advised, adequate sampling and analysis of cherts with methods such as INAA and discriminant analysis are necessary to over-ride the high levels of chemical variation that interfere with the discrimination of source outcrops. Naturally, the ultimate proof of a lithic source analysis lies in the success of its results.

Thus, during the fall of 1987, a systematic sample of chert specimens was taken from a stratigraphically correlated series of outcrops along the Onondaga Escarpment from Buffalo east to Akron, New York (Fig. 1). An outlier from Oaks Corners was later added to detect regional variation. In all some 150 pieces were collected from seven localities. Samples were then run through INAA. The concentration data measured for sixteen elements were analyzed visually, and through discriminant analysis, to find patterned variation suitable for distinguishing Onondaga chert outcrops, and ultimately to facilitate the sourcing of prehistoric artifacts.

Geological background

A brief discussion of the geological background will aid in understanding the problem. Onondaga chert occurs in the Onondaga Limestone, a Middle



Sample locations:

1. E. Amherst St. 6. Oaks Crnrs. Qu. Rdct. 7. Centerpointe
2. Williamsville 8. Guenther Site
3. Goodrich Rd. 9. French 3 Site
4. Akron Falls 10. H. Long Site
5. E. Amherst St.

FIGURE 1
Map of the study area

Devonian formation which underlies the southern half of New York State, parts of southwestern Ontario and northern Pennsylvania (Oliver 1966). The formation has been divided into four members, in order of deposition: Edgecliffe, Clarence (Nedrow in eastern New York), Seneca, and Moorehouse. While chert is extremely common in the Clarence member, often exceeding 50% by mass, by contrast, in the Edgecliffe member, it averages less than 5%. The chert proportions of the Seneca and Moorehouse members lie between these values (Dunn and Ozol 1963).

In the study area, glacial action eroded most of the Seneca and Moorehouse members, so only the Clarence and Edgecliffe members remain exposed in the outcrops and stream cuts of the Onondaga Escarpment (Buehler and Tesmer 1963). This escarpment runs east to west across New York State, and presumably provided as easy an access to the chert for prehistoric Indians as it does today for geologists and archaeologists (Fig. 1). In the western part of the state, this resource is abundant, but east of Rochester, where the scarp is less pronounced, the chert becomes rather scarce. While Dunn and Ozlo (1962:19) indicate strata consisting of 25% and even 40% chert in the Phelps area, at Oaks Corner Quarry, where over forty metres of the Onondaga formation is exposed, only rare nodules were observed and these were high in the Moorehouse member. East of Syracuse, the chert again becomes plentiful.

In the study area, Onondaga chert of the Clarence/Nedrow and Edgecliffe members varies from medium light grey to greyish black in colour (Munsell N6 to N2). The scarcer chert in the other members is usually darker, but can also be a tan hue (Hammer 1976; Wray 1948). Chert quality can vary considerably. In some deposits it is unsuitable for knapping due to frequent inclusions and stress flaws, while in others, the material has a good, even texture and an excellent conchoidal fracture. For this study, no attempt was made to sample only the sources of highest quality chert, since the goal was to characterize the whole resource, not just a few outcrops. A followup study should be made to delineate the availability of desirable chert, similar to projects conducted by Odell (1984) and Meyers (1970) in the Illinois Valley.

Archaeological background

The use of trace element analysis to establish lithic provenance has become quite common in North American archaeology. For example, there are studies of Southwestern obsidian (Findlow and Bolognese 1982; Griffin *et* al. 1969) and turquoise (Sigleo 1975; Weigand *et al.* 1977), Kettle Point chert (Janusas 1984) and quartzite (Julig *et al.* 1987) from Ontario, and Pennsylvania jasper (Hatch and Miller 1985; Luedtke 1987b). However, the application of these methods to New York State materials has been limited to a handful of studies (Brindle and Hancock 1987; Koffyberg 1987; Kuhn and Lanford 1987; Luedtke 1976; Pavlish et *al.* 1987), none of which has intensively addressed the Onondaga material.

Although studies utilizing the more traditional macroscopic and microscopic approaches have shown clear distinctions between Onondaga and other Northeastern cherts (e.g. Hammer 1976; Koffyberg 1987; Kuhn and Lanford 1987; Lavin 1983; Parkins 1974, 1977; Wray 1948), when these methods have been directed solely at Onondaga chert, *they* have only managed to distinguish samples from opposite ends of the formation (Hammer 1976; Lavin and Prothero 1981; Wray 1948), and samples from different members of the formation (Owl 1963). Yet despite the absence of an adequate basis for the sourcing on Onondaga chert and artifacts, there is a tendency in the literature (e.g. Ritchie 1980:8) to link artifacts to well-known but insufficiently studied prehistoric quarries, such as those at Divers Lake in western New York (Prisch 1976), and at Coxsackie in the east (Parker 1925; Laccetti 1989).

Method

A small series of outcrops situated along the Onondaga Escarpment were chosen, but only locations that could be correlated stratigraphically were sampled. For this study, only New York State material was used. Here, the geological literature proved valuable, particularly the New York State Geological Association (NYSGA) annual fieldtrip guidebooks. To make matters easier, the escarpment usually exposes not only the Onondaga formation, but also its basal disconformity with the Upper Silurian Lockport dolomites. This contact is a consistent stratigraphic horizon across the state. It is readily visible to the eye, and thus forms a natural reference point for controlled sampling.

The seven locations sampled were: a roadcut and adjacent old quarry on East Amherst Street, Buffalo; the banks of Ellicott Creek at Glen Park Falls, and residual surface material from the nearby Centerpointe Site, both in Williamsville; the cut which Goodrich Road makes through the escarpment in Clarence; the walls of Murder Creek at Akron Falls, Akron; and the active General Crushed Stone Co. Quarry in Oaks Corners (Fig. 1). This last sample was included to provide data on longer range variations in the formation.

At each locality, a geologist's hammer was used to take a sample of every nodule lying near an arbitrarily defined vertical line established from the point of Lockport dolomite contact to the top of the exposure. On average, between fifteen and twenty samples were removed from a six metre section of the formation. Each piece's original location in the sampling series was noted for future reference. Studies such as Janusas' (1984:82) characterization of Kettle Point chert, have encountered problems in obtaining conclusive results because they have not analyzed adequate sample sizes. Typically, statistical analyses require a minimum of ten cases per sample, while more are required to reduce standard error. Although several of this study's samples are barely over these minimum limits, they should prove sufficient for exploratory research.

In the lab, knapping quality was estimated for all the samples collected, based on past experimental observations that the most desirable material has a fine texture, an absence of inclusions, and an excellent conchoidal fracture. From the best material present in each piece, a 200-300 milligram sample was detached using a sandstone cobble. The outermost material was first removed to avoid contamination that might be present on the surface of the piece.

Although a variety of techniques are available for elemental analysis of lithic materials, INAA has many advantages for chert sourcing. It has a high accuracy and is the most sensitive technique for measuring low elemental concentrations. It has the capacity for simultaneous analysis of many elements. Because it measures the whole of a sample, not just the surface, as in the X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques, INAA is also less subject to errors from any accidental focus on the inclusions or other small-scale chemical heterogeneities which seem to occur frequently in Onondaga chert. And it is conveniently easy to conduct for relatively untrained operators, such as archaeologists (Harbottle 1982).

In INAA, samples are placed in inert plastic capsules and fired through a pneumatic tube into the reactor. There, they are exposed to a thermal neutron bombardment for a set period of time during which certain radioactive isotopes are formed. The samples are then removed and placed in front of a counter which detects and counts the decay products which are emitted as the excited atoms in the radioisotopes return to a normal state. Through knowledge of a particular element's reaction habits, its concentration in a sample can be quite easily determined.

For this study, INAA was conducted at the SLOWPOKE Reactor Facility at the University of Toronto, between January and March of 1988. The chert was irradiated for five minutes at five kilowatts, then exposed to a germanium-lithium detector for gamma ray counting.

Sixteen elements were measured: uranium, dysprosium, barium, titanium, strontium, iodine, bromine, magnesium, silicon, sodium, vanadium, potassium, aluminum, manganese, chlorine, and calcium. Their concentrations by mass were reduced from the raw gamma ray counts with an *Apple 2e* computer using the comparator method and in-house standards. Of the elements measured, strontium and iodine fell outside the detection limits in over half the cases, and have thus been excluded from the analysis. For the final stage of analysis, the data were. loaded on to the IBM mainframe computer at the State University of New York at Buffalo and examined using the Statistical Package for the Social Sciences (Norusis, 1985).

Trends in the data

The descriptive statistics for the geological outcrops sampled are shown in Table 1. The proportions of the trace elements present are given as parts per million (ppm), except for magnesium, sodium, potassium and aluminum, where they are given as percentages. A general increase in elemental concentrations is apparent as one proceeds eastward through the population. The most expressive examples of this trend are the bromine, chlorine, and sodium levels. The scattergrams in Figure 2a (the bivariate plot of bromine by chlorine) and Figure 2b (graphing sodium by chlorine) clearly show these trends. The East Amherst Street (Buffalo) and Glen Park Falls (Williamsville) samples have the lowest values and are spread across the centre and lower left of the scattergrams. The Goodrich Road (Clarence) and Centerpointe Site (Williamsville) samples have higher values, and cluster just right of centre. The Akron Falls (Akron) and Oaks Corners (Phelps) samples have the highest overall values and form distinct clusters to the far right. Also visible is the strong linear relationship among these three elements. Their correlations have Pearson's coefficients greater than 0.8 (one-tailed), and are highly significant with the probability much less than .05.

In geology, changes through the sedimentary formation are termed a facies shift. They are the product of the local environmental conditions which existed during deposition, such as depth, turbidity, and distance from the shore, and which influenced the type and proportion of organic and inorganic materials which now form the rock. In the Onondaga chert samples, the increasing concentrations of elements typical for clay minerals (aluminum, magnesium, and potassium) suggest an elevation in the proportion of clay in the original sediment. Since clay enters marine waters through rivers and settles near the shore, an increasing clay content could correlate with a general proximity to shore, or a more specific proximity to a major fresh water outlet. The increasing levels of chlorine and sodium could reflect the depositional environment, or they may relate to chemical processes active during chert formation. While more study would be required to explain this trend, its very existence provides the means for the characterization of Onondaga cherts.

Archaeological applicability

To test the applicability of this study to archaeology, a sample of ten chert flakes was collected from each of three western New York State sites: French 3 (18 kilometres south of the scarp), Guenther (6 km south of the scarp), and Henry Long (1 km from the scarp) (Fig. 1). The flakes were chosen to rep-resent knapping activities early in the reduction sequence so as to bias the samples toward site-local materials (assuming that preliminary reduction of a raw material occurs near its source). This material was analyzed similarly to the geological samples, except that steel pliers were used as a vise while pieces were struck using the sandstone cobble. Unlike the procedure followed with the thicker geological samples, the outer surfaces of the flakes were not removed. The archaeological artifacts are thus not safe from the effects of any chemical reactions which may have occurred between the

All geological samples (120 cases)

	U	Dy	Ti	Br	Mg%	Na%	V	K%	A1%	Mn	Cl
M	.463	.151	135	11.30	.200	.070	4.75	.101	.409	16.20	1090
S	.109	.074	48	4.60	.062	.023	2.23	.076	.082	9.50	430
R	.699	.459	300	26.20	.334	.111	10.20	.341	.439	59.40	2130

East Amherst Street (49 cases)

	U	Dy	Ti	Br	Mg%	Na%	V	K%	Al%	Mn	Cl
M	.443	.135	121	9.10	.182	.061	4.07	.079	.404	11.50	864
S	.077	.047	50	2.40	.056	.014	1.63	.070	.082	3.50	209
R	.367	.259	249	12.10	.277	.090	8.02	.288	.354	16.80	997

Williamsville (15 cases)

	U	Dy	Ti	Br	Mg%	Na%	V	K%	Al%	Mn	CI
M	.435	.177	132	9.50	.222	.061	4.76	.085	.401	20.60	935
S	.158	.106	38	1.70	.058	.008	2.15	.068	.064	14.30	142
R	.630	.459	121	5.90	.198	.027	6.45	.174	.228	56.80	539

Centerpointe Site (16 cases)

	U	Dy	Ti	Br	Mg%	Na%	V	K%	Al%	Mn	Cl
M	.469	.122	112	11.00	.195	.060	2.84	.105	.335	12.10	1070
S	.092	.039	36	3.10	.045	.015	.79	.053	.061	1.80	104
R	.287	.178	152	14.30	.189	.055	2.74	.198	.217	6.90	314

Goodrich Roadcut (19 cases)

	U	Dy	Ti	Br	Mg%	Na%	V	K%	Al%	Mn	Cl
M	.435	.184	142	10.40	.178	.067	5.83	.121	.426	15.90	1050
S	.042	.043	27	2.10	.040	.016	1.73	.068	.064	3.30	240
R	.125	.158	112	8.80	.138	.066	5.91	.262	.214	14.20	940

Akron Falls (12 cases)

	U	Dy	Ti	Br	Mg%	Na%	V	K%	A1%	Mn	Cl
M	.609	.214	186	15.90	.216	.102	8.42	.197	.505	27.70	1800
S	.151	.113	54	4.60	.078	.025	2.46	.073	.079	14.40	550
R	.526	.450	213	16.7	.259	.088	7.23	.235	.261	48.30	1940

Oaks Corner Quarry (9 cases)

	U	Dy	Ti	Br	Mg%	Na%	V	K%	*A1%*	Mn	Cl
M	.468	.085	167	22.60	.287	.113	4.60	.062	.417	26.90	1690
S	.095	.085	29	2.30	.060	.009	1.03	.076	.034	6.90	596
R	.338	.211	110	6.20	.196	.026	3.64	.174	.117	23.20	1990

TABLE 1

Descriptive statistics for geological samples

Key: M = sample mean; S = sample standard deviation; R = sample range; ppm unless noted

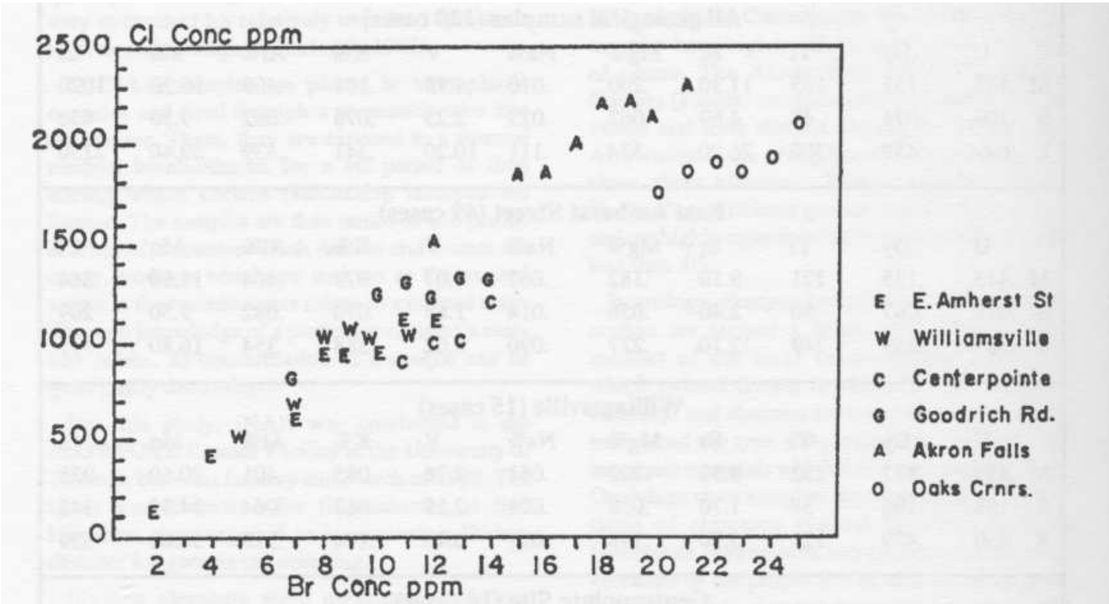


FIGURE 2a
Plot of Cl by Br for geological samples

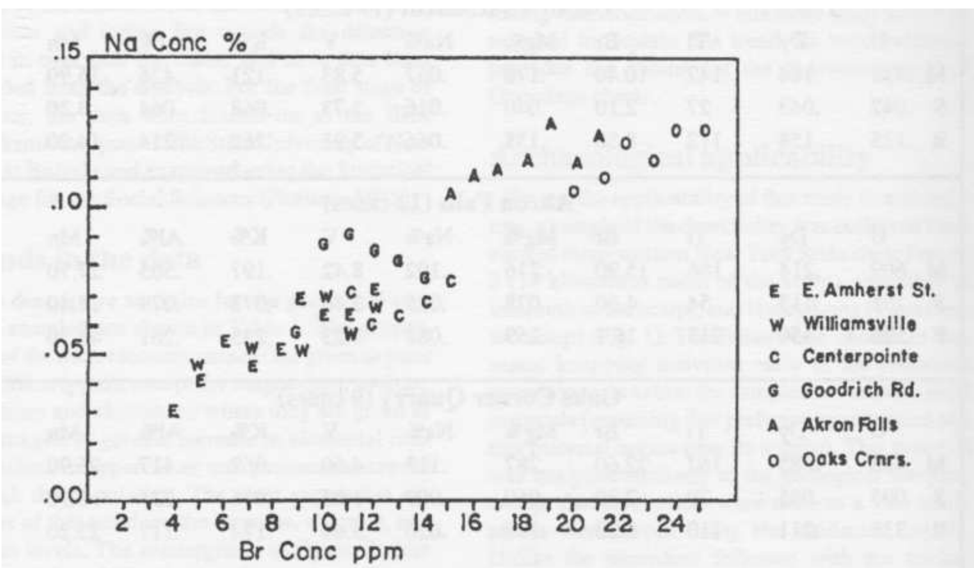


FIGURE 2b
Plot of Na by Br for geological samples

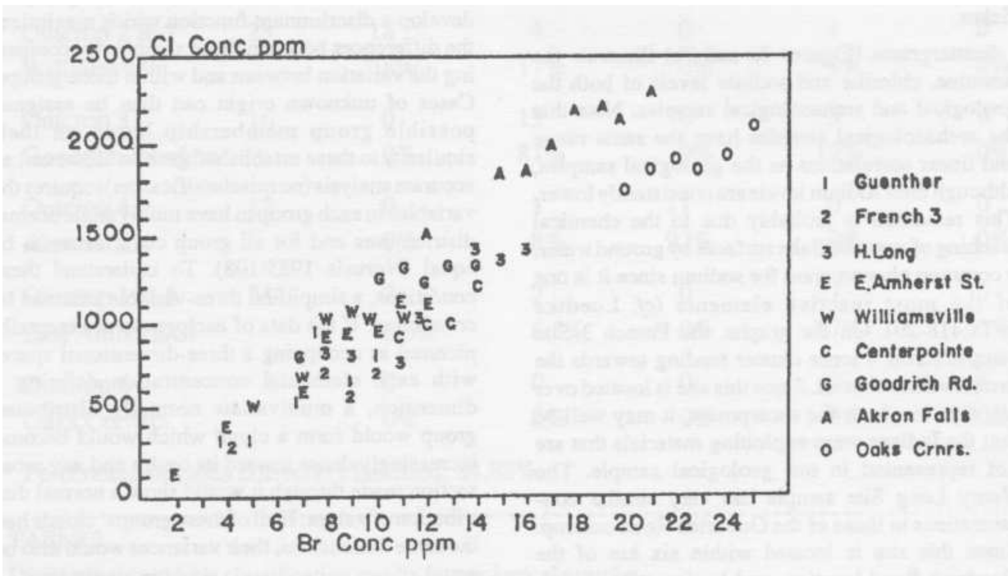


FIGURE 3a

Plot of Cl by Br for all samples

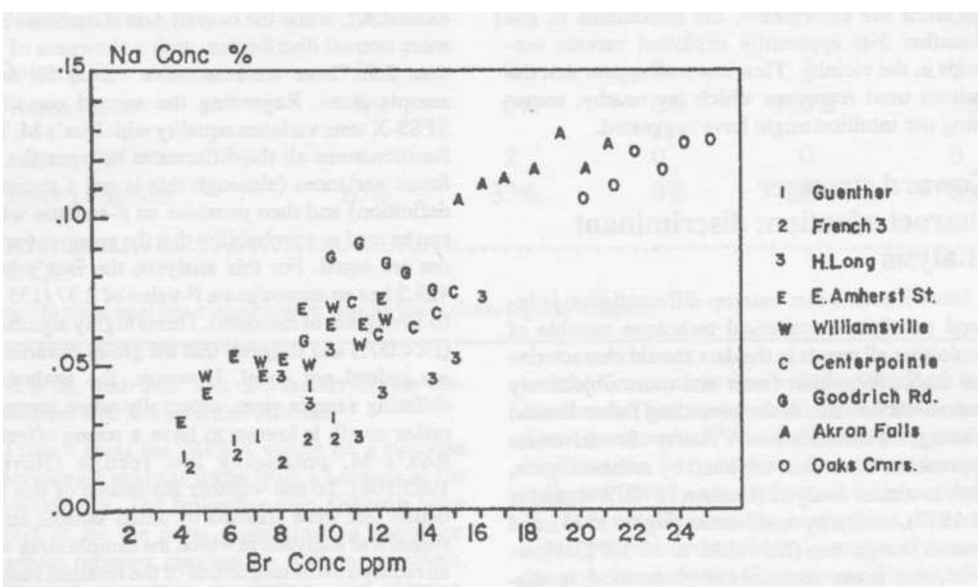


FIGURE 3b

Plot of Na by Br for all samples

chert and the surrounding soil and ground water. Such interactions can alter the concentrations of susceptible elements on the outer surfaces of the flakes.

Scattergrams (Figures 3a and 3b) illustrate the bromine, chlorine and sodium levels of both the geological and archaeological samples. Note that the archaeological samples have the same range and linear correlations as the geological samples, although their sodium levels are consistently lower. This reduction is probably due to the chemical leaching of exposed flake surfaces by ground water, a common phenomenon for sodium since it is one of the most reactive elements *(cf.* Luedtke 1978:418-20). On the graphs, the French 3 Site sample forms a loose cluster tending towards the lowest values overall. Since this site is located over eighteen km from the escarpment, it may well be that the Indians were exploiting materials that are not represented in our geological sample. The Henry Long Site sample has very similar concentrations to those of the Goodrich Road outcrop. Since this site is located within six km of the Goodrich Road location, and is almost on the escarpment, the data probably reflect site-local chert acquisition. The Guenther Site data are dispersed, overlapping the values of the East Amherst Street, Williamsville, and Goodrich Road samples. Lacking an immediate chert source, but being only six km from the escarpment, the inhabitants of the Guenther Site apparently exploited various outcrops in the vicinity. Thus it would appear that the Indians used resources which lay nearby, something our intuition might have suggested.

Toward stronger characterization: discriminant analysis

Since it seems that outcrop differentiation is indeed possible, a statistical technique capable of exploiting all trends in the data should characterize the whole formation faster and more objectively than methods such as the preceding rather limited scattergram examination. A variety of multivariate approaches have been explored by archaeologists, such as cluster analysis (Hodson 1970; Weigand et *al.* 1977), similarity coefficients (Sigleo 1975), and pattern recognition (Kowalski *et al.* 1972). However, the most recommended method is discriminant analysis (Harbottle 1982; Luedtke 1979; Ward 1974) and so it was chosen for this study. SPSS-X (Norusis 1985) was used to apply discriminant analysis to the data.

Discriminant analysis transforms trends in multiple variables into a more easily examined single variable. It uses sample data from known groups to develop a discriminant function which maximizes the differences between those samples by comparing the variation between and within those groups. Cases of unknown origin can then be assigned possible group membership based on their similarity to these established groups. However, an accurate analysis (no misclassification) requires the variables in each group to have multivariate normal distributions and for all group covariances to be equal (Norusis 1985:108). To understand these conditions, a simplified three-variable case can be considered. If the data of each group are mentally pictured as occupying a three-dimensional space, with each elemental concentration defining a dimension, a multivariate normally distributed group would form a cloud which would become increasingly dense toward its centre and any cross section made through it would show a normal distribution of values. If all of these groups' clouds had the same dimensions, their variances would also be equal.

For this study, an examination of the data showed that a few of the groups' variable distributions were not normal due to skewed samples. However, after removal of all cases which did not meet their INAA detection limits, these skewness values did not exceed 3.7, while the overall data showed an even more normal distribution, with a skewness of less than 2.5. These are reasonable values for small sample sizes. Regarding the second condition, SPSS-X tests variance equality with Box's M. This function sums all the differences between the different variances (although this is not a statistical definition) and then provides an F-statistic which can be read as a probability that the group covariances are equal. For this analysis, the Box's M of 429.2 has an approximate F-value of 2.37 (135 and 6130 degrees of freedom). This is highly significant (P«.001) and suggests that the group covariances are indeed not equal. However, the analysis of differing sample sizes, especially when some are rather small, is known to have a strong effect on Box's M, producing low results (Norusis 1985:108). To test whether the results of this particular test were affected by small sample size, a subset was analyzed in which the sample sizes were all reduced to the magnitude of the smallest sample. Discriminant analysis of this subset produced almost identical results to the previous larger analysis. This second test suggests that the differing sizes of the samples was influencing the result of

Actual outcrop	No. of cases	Predicted 2 & 7	3	Outcrop 4	Membership 1 & 5	6
Outcrop 2& 7 Williamsville	23	18 78%	4 17%	0 0%	1 4%	0 0%
Outcrop 3 Goodrich Roadcut	16	0 0%	13 81%	0 0%	3 19%	0 0%
Outcrop 4 Akron Falls	12	0 0%	1 8%	11 92%	0 0%	0 0%
Outcrop 1 & 5 East Amherst St	31	2 6.5%	2 6.5%	0 0%	27 87%	0 0%
Outcrop 6 Oaks Corners	4	0 0%	0 0%	0 0%	0 0%	4 100%

Percentage of cases correctly classified: 84.88%

TABLE 2
Discriminant analysis classification results for geological samples

Actual outcrop	No. of cases	Predicted 2 & 7	3	Outcrop 4	Membership 1 & 5	6
Outcrop 8 Guenther Site	7	2 29%	1 14%	0 0%	4 57%	0 0%
Outcrop 9 French 3 Site	3	0 0%	0 0%	0 0%	3 100%	0 0%
Outcrop 10 Henry Long Site	6	4 67%	2 33%	0 0%	0 0%	0 0%

TABLE 3
Discriminant analysis classification results for archaeological samples

Box's M, and thus that the results of the discriminant analysis are valid after all.

Table 2 gives the SSPS-X output for a stepwise discriminant analysis using Wilk's Lambda as the discriminator. The following nine elements were found to be the most discriminating variables: uranium, bromine, magnesium, sodium, vanadium, potassium, aluminum, manganese, and chlorine. Initial runs of the discriminant analysis showed a large overlap between the assignments from two pairs of closely situated samples (the East Amherst Street quarry with the East Amherst Street roadcut, and the Centerpointe Site with the Glen Park Falls locations). They were joined into an East Amherst Street group and a Williamsville group respectively. Since the East Amherst Street samples were collected literally across the road from each other and from the same stratigraphic position, they could actually have been considered samples of the same outcrop. Similarly the Centerpointe Site and Glen Park Falls samples could easily have been one sample. They originated across the creek from each other (less than two km apart) and from the same strata, and they are related both visually and chemically. By reducing the level of error, these combinations considerably strengthened the discriminant analysis results discussed below. This pooling in no way threatens the validity of the study, since the remaining samples lie much farther apart, over eight km, and are chemically easy to differentiate. The Oaks Corners sample could have been removed at this stage in the study due to its rather small size. However, this was not necessary as its data contributed the least error to the study, probably due to its distant origin.

Table 2 contains the discriminant analysis results. The overall classification success rate is very high, just under 85%. For the Williamsville samples, the accuracy was over 78%, although a few cases were incorrectly categorized as being from the nearby Goodrich Road (17%) or East Amherst Street (4%) sources. The Goodrich Road sample was correctly classified for over 81% of its cases; the remaining 19% were wrongly assigned to the East Amherst Street source. Ninety-two percent of the Akron Falls cases were accurately classified, and only 8% (one case) was mis assigned to the nearby Goodrich Road source. Interestingly, no cases from any of the other samples was incorrectly assigned to Akron Falls. Over 87% of the East Amherst Street cases were accurately classified, the remaining 13% being incorrectly assigned, half to the nearby Williamsville locations and the other half to the Goodrich Road location. All of the Oaks Corners Quarry cases were correctly classified and no cases from any of the other samples was wrongly assigned to this locality.

Overall, the most easily isolated samples are those from Oaks Corners and Akron. The East Amherst Street and Goodrich Road samples, occurring only twenty km apart, are easily distinguished, as is the Akron Falls sample from that of Goodrich Road, only fifteen km away. Even the worst success rate, from the Williamsville samples, lies in the high seventies, and these samples can easily be differentiated from any of the localities which are ten or more km away.

In order to source the archaeological samples, their data were added to a repeat of the first analysis, generating the results shown in Table 3. Two-thirds *(67%)* of the Henry Long Site cases were assigned to Williamsville and 33% to Goodrich Road. The site is situated just south of the escarpment, six km southeast of Goodrich Road, but seventeen km from the Williamsville locations. Of the Guenther Site cases, 57% were assigned to East Amherst Street, 29% to Williamsville, and 14% to Goodrich Road. Guenther is located six km south of the scarp and the Goodrich Road location, ten km from the Williamsville locations, but roughly fourteen km from East Amherst Street. Finally, 100% of the French 3 Site cases were assigned to the East Amherst Street source. French 3 is situated eighteen km south of the scarp and twenty-four km from the East Amherst Street location. No resemblances occur between any of the artifacts and the Akron or Oaks corners material.

The disadvantage of discriminant analysis is its need to assign unknowns to the most similar sample group for which it has data. The analysis is not designed to isolate any samples as dissimilar to the established groups. Thus, because of the distance of the Guenther and French 3 sites from the escarpment, and their generalized similarity to the closest outcrops, I would recommend a more extensive geological sampling before making conclusive statements regarding their artifacts' sources. Such a study is being planned. It would also be wise to run site-local geological samples alongside any archaeological material. It is interesting to note that the patterns seen in the scattergams are repeated. Again the Guenther Site sample shows connections to the East Amherst Street, Williamsville, and Goodrich Road locations. Some Henry Long material resembles the Goodrich Road chert, but most matches that from the Williamsville locations. These are the two closest outcrops. And finally, all of French 3 is linked to the closest outcrop, East Amherst Street.

Summary and conclusions

Systematic sampling of Onondoga chert outcrops and chemical characterization by INAA have been productive. Visible in the data are systematic changes in the concentrations of a suite of elements, in particular bromine, chlorine, and sodium, which show a general increase eastward across the study area, indicating a facies shift in the formation. Discriminant analysis was able to distinguish where the geological samples originated in 85% of the cases. Archaeological samples from the French 3, Guenther, and Henry Long sties were also analyzed. While no singular matches with outcrops were established, the assignments made are in keeping with the results both of visual evaluation of the data and with intuition.

These results are highly significant for western New York State archaeology. By this approach, differences were observed between outcrops separated by short distances, in some cases much less than 10 km, where **previously** no measure of Onondaga chert provenance was possible. The examination of chert movement over quite small distances would now appear to be possible.

In the future, however, sampling of cultural material will have to be more rigorous to control for phenomena such as the chemical leaching which was observed in the artifacts used in this study. While the study's overall results look very promising, extension of the geological data bases will be necessary to elucidate whether fingerprinting of the whole Onondaga Formation is feasible. Currently, the data base is being expanded with material from southwestern Ontario, and from New York State outcrops located farther to the east, while repeat sampling of the original locations will augment and thus strengthen the original data.

Acknowledgements

This paper summarizes the research made for my Master's thesis. An earlier version of this paper was presented at the North Eastern Anthropological Association annual meeting, in Montreal, Quebec, in 1989.

Many thanks are due to my advisor, Sarunas Milisauskas, and the staff of the SLOWPOKE Reactor Facility. The warm encouragement and helpful advice of Ian Brindle, Barbara Calogero, Frank Cowan, Ron Hancock, Jack Holland, Barbara Luedtke, Margaret Nelson, Bill Parkins, Larry Pavlish, Kathryn Stark, Ken Tankersley, Ezra Zubrow (a multitude of others) and especially my family, were tremendously appreciated.

Funding for most of the project was contributed as a grant by the Diamond Research Fund of the Graduate Students' Association of the State University of New York at Buffalo. Archaeological samples were generously donated by the Department of Anthropology's Marian E. White Museum, and by Eric Hansen of Hansen and Associates' Archaeological Consulting on behalf of the Cimminelli Corporation (Centerpointe Site). Permission for geological sampling was contributed by the Buffalo Department of Public Works and by the General Crushed Stone Company.

References cited

Brindle, Ian and R. G. V. Hancock
1987 INAA of Cherts. Abstract in *Annual Report of the SLOWPOKE Reactor Facility*, July, 1986 to June, 1987. (University of Toronto).

Buehler, Edward J. and Irving H. Tesmer
1963 *Geology of Erie County.* Buffalo Society of Natural Sciences Bulletin 21 (3).

Dunn, James R. and Michael A. Ozol
1962 Deleterious Properties of Chert. *Physical Research Report No. 12.* Rensselaer Polytechnic Institute (Troy).

Findlow, Frank J. and Marisa Bolognese
1982 Regional Modelling of Obsidian Procurement in the American Southwest. In: J. E. Ericson and T.K. Earle (eds.) *Contexts for Prehistoric Exchange.* (Academic Press): 53-81.

Griffin, James B., A. A. Gordus, and G. A. Wright
1969 Identification of the Sources of Hopewellian Obsidian in the Middle West. *American **Antiquity*** 34 (1): 1-14.

Hammer, John
1976 Identification and Distribution of Some Lithic Raw Materials from New York State. *Man in the Northeast* 11:39-62.

Harbottle, Garman
1982 Chemical Characterization in Archaeology. In: J. E. Ericson and T. K. Earle (eds.) *Contexts for **Prehistoric Exchange.*** (Academic Press):13-51.

Hatch, James, and Patricia Miller
1985 Procurement, Tool Production, Sourcing Research at the Vera Cruz Jasper Quarry **in Pennsylvania.** ***Journal** of Field Archaeology* 12:219-230.

Hodson, F.R.
1970 Cluster Analysis and Archaeology: Some New Developments and Applications. *World Archaeology* 1 (3):299-321.

Janusas, Scarlett E.
1984 A Petrological Analysis of Kettle Point Chert and its Spatial and Temporal Distribution in Regional Prehistory. National Museum of Man Mercury Series. *Archaeological Survey of Canada Paper 128.*

Julig, P. J., L. A. Pavlish, and R. G. V. Hancock
1987 Instrumental Neutron Activation Analysis of Archaeological Quartzite from Cummins Site Thunder Bay: Determination of Geological Source. *Current Research in the Pleistocene* 4:59-61.

Koffyberg, Agnes M. J.
1987 *Comparison of Three Chert Types of **the Niagara Region Using Petrographical and Chemical Methods.*** Unpublished B.A. thesis, Department of Chemistry, Brock University.

Kowalski, B. R., F. Schatzki, and F. H. Stross
1972 Classification of Archaeological Artifacts by Applying Pattern Recognition to Trace Element Data. *Analytical Chemistry* 44 (13):2176-80.

Kuhn, Robert D. and William A. Lanford
1987 Sourcing Hudson Valley Cherts from Trace Element Analysis. *MINE* 34:57-69.

Laccetti, Michael F.
1989 The Meier Site: A Chert-Knapping Workshop at Flint Mine Hill, Coxsackie, New York. *New York State Archaeological Association Bulletin* 98:25-35.

Lavin, Lucianne M.
1983 *Patterns of Chert Acquisition Among Woodland Groups Within the Delaware Watershed: A Lithologic Approach.* Unpublished PhD Dissertation. Department of Anthropology, New York University.

Lavin, Lucianne M. and Donald R. Prothero
1981 Microscopic Analysis of Cherts Within and Adjacent to the Delaware River Watershed. *MINE* 21:3-17.

Luedtke, Barbara E.
1976 *Lithic Material Distributions and Interaction Patterns During the Late Woodland Period in Michigan.* Unpublished PhD Dissertation. Department of Anthropology, University of Michigan.
1978 Chert Sources and Trace Element Analysis. *American Antiquity* 43 (3):413-23.
1979 The Identification of Sources of Chert Artifacts. ***American Antiquity*** 44 (4):744-57.
1987b The Pennsylvania Jasper Connection Jasper at Massachusetts Sites. *Massachusetts Archaeological Society Bulletin* 48 (2):37-47.
1987a *Chert Source Determination: Getting Down to Basics.* Paper presented at the annual meeting of the Society for American Archaeology, Toronto, Ontario.

Meyers, J. Thomas
1970 Chert Resources for the Lower Illinois Valley: A Study of Chert Raw Material Distributions and Their Implications for Prehistoric Man. *Illinois Valley Archaeological Program. Research Papers Vol. 2. Reports of Investigations No. 18* (State of Illinois, Springfield).

Norusis, Marija J.
1985 *SPSS-X Advanced Statistics Guide* (SPSS-X, Chicago).

Odell, George
1984 Chert Resource Availability in the Lower Illinois Valley: A Transect Sample. In: B. M Butler and E. E. May (eds.) *Prehistoric Chert Exploitation: Studies from the Midcontinent. Center for Archaeological Investigations, Occasional Paper 2. (SIU, Carbondale):45-67.*

Oliver, William A. Jr.
1966 Bois Blanc and Onondaga Formation in Western New York and Adjacent Ontario. In: E. J. Buehler (ed.) *NYSGA **Guidebook** of **the** 38th **Annual** Meeting:32-43.*

Ozol, Michael A.
1963 *Alkali Reactivity of Cherts and Stratigraphy and Petrology of Chert: and Associated Limestones of the Onondaga Formation of Central and Western New York.* Unpublished Ph[Dissertation. Department of Geology Rensselaer Polytechnic Institute.

Parker, Arthur C.
1925 The Great Algonkin Flint Mines at Coxsackie. ***Researches and***

*Transactions of **the** NYSAA L. H. Morgan Chapter* 4 (4).

Parkins, William G.
1977 *Onondaga Chert: Geological and **Palynological Studies** as Applied to Archaeology.* Unpublished Master's Thesis. Department of Geology, Brock University.
1974 *Source of Chert from Welland River Archaeological Sites.* Unpublished Bachelor's Thesis. Department of Geology, Brock University.

Pavlish, L. A., R. G. V. Hancock, P. Julig, and A. C. D'Andrea
1987 Systematic, Stratified INAA of Two Chert Outcrops in Southern Ontario. ***Annual** Report of **the** SLOWPOKE **Reactor Facility.** July '86 to **June** '87.* (University of Toronto).

Prisch, Betty C.
1976 The Divers Lake Quarry Site. *New York State Archaeological Association Bulletin* 66:8-18.

Ritchie, William A.
1980 *The Archaeology of New York State* (Revised Edition). (Harbor Hill Books).

Sigleo, Anne C.
1975 Turquoise Mine and Artifact Correlation for Snaketown Site, Arizona. *Science 189:459-60.*

Ward, G.K.
1974 A Systematic Approach to the Definition of Sources of Raw Materials. *Archaeometry* 16 (1):41-53.

Weigand, Phil C., Garman Harbottle, and Edward V. Sayre
1977 Turquoise Sources and Source Analysis: Mesoamerica and the Southwestern U. S. A. In: T. K. Earle and J. E. Ericson (eds.) *Exchange **Systems in** Prehistory* (Academic Press).

Wray, Charles F.
1948 Varieties and Sources of Flint Found in New York State. *Pennsylvania Archaeologist 18* (1-2):25-43.

Hugh W. Jarvis
Anthropology Department
State University of New York at Buffalo
Amherst, New York 14261