Geological Sourcing of Volcanic Stone Adzes from Neolithic Sites in Southeast China

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INTRODUCTION

SEAFARING BEGAN AS EARLY AS 6000 YEARS AGO in southeast China, but archaeological remains of watercraft dating to this period are scarce. The best evidence for early voyaging may derive instead from the reconstruction of prehistoric exchange networks. The recent discovery of a Neolithic adze production center in the Penghu Islands (P'eng-hu or Pescadores) identifies an important component of this exchange system (Rolett et al. in press). Chemical analysis of artifacts and associated geological samples collected at the Penghu adze workshops establishes a direct link between these sites and archaeologically recovered basalt adzes from the southwest coast of Taiwan. Systematic transport of stone adzes from Penghu to Taiwan required regular contact across an open-sea channel spanning 65 km. This seafaring began at least 4000 years ago. It is significant as the earliest evidence for systematic open-sea voyaging in the Taiwan Strait.

In contrast to the emerging record of Neolithic contact between Penghu and Taiwan, very little is known about exchange networks on the coast of Mainland China. In part this is because evidence for the Neolithic exchange of stone tools is less visible on the mainland than in Taiwan. The southwest coast of Taiwan consists mainly of limestone, and—since there is no local source of volcanic stone—the archaeologically recovered basalt adzes are readily identified as imports. On the other hand, the coast of Mainland China is geologically complex, with abundant sources of volcanic and metamorphic rock suitable for the production of stone tools. Stone adzes are common in Neolithic sites on the coast of Mainland China. Were these tools exchanged over long distances? Our research investigates this problem through the same interdisciplinary archaeological and geological approach used to document Neolithic contact between the Penghu Islands and Taiwan.

Our methodology involves XRF (X-ray fluorescence) and ICP-MS (inductively coupled plasma mass spectrometry) analyses to determine the chemical

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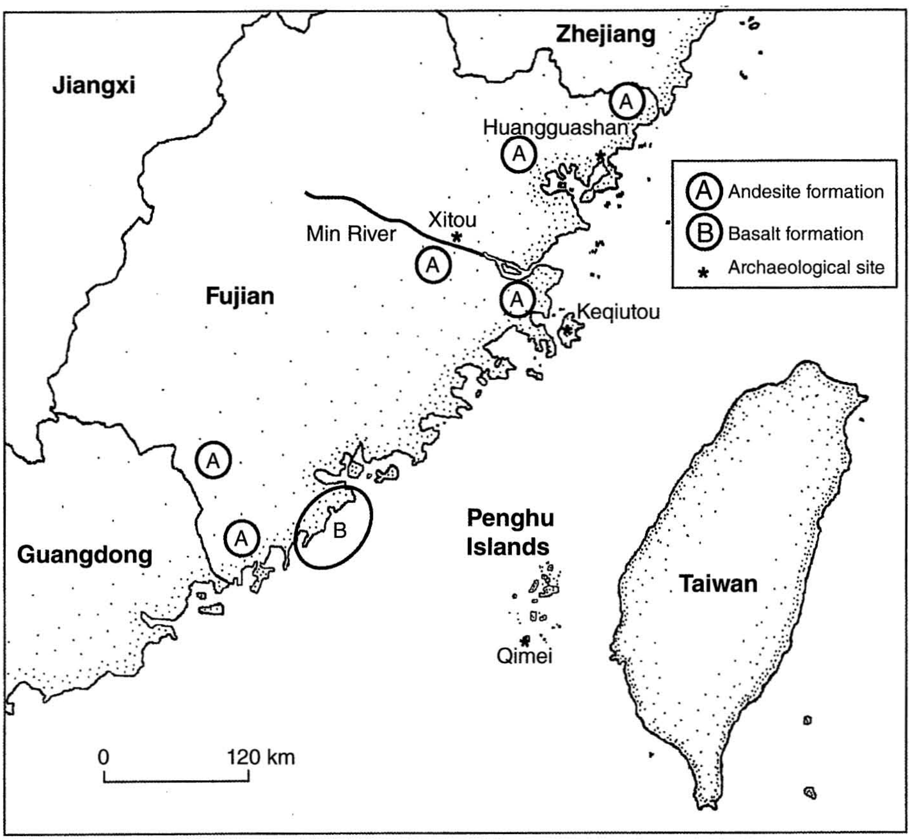

Fig. 1. Map of southeast China.

composition of raw material used in stone tool production. These analyses give a chemical "fingerprint" of adzes so that they can be compared with each other, as well as with geological reference specimens from known locations. In this way we can identify locations where the adzes were produced. We can also determine if adzes were transported from the production areas to other places.

The work presented here is part of a collaboration involving the Fujian Provincial Museum, the Chinese Academy of Sciences, the University of Hawai'i, Harvard University, and the Bernice P. Bishop Museum (Guo et al. 2005; Rolett et al. 2002). This particular study focuses on adzes from three Neolithic sites located on the Fujian coast of Mainland China, opposite Taiwan (Fig. 1). All three sites (Huangguashan, Xitou, and Keqitou) were first excavated in the 1980s (Lin 2003), and we recently returned to two of them (Huangguashan and Keqitou) for renewed investigations (Lin et al. 2004). The artifact collections are housed in the Fujian Provincial Museum. We selected these sites because they represent different locations and a range of time periods dating to between 6500 and 3500 B.P. Although all of the sites contain adzes, the excavations have not yielded lithic debitage associated with adze production.

Artifact assemblages from the Huangguashan (3500–4300 B.P.) and Xitou (4300–5000 B.P.) sites contain large numbers of skillfully worked, polished adzes made of fine-grained rock (Lin 2003). This is notable because adze sourcing research in Polynesia shows that, in general, well-finished adzes made of high-quality raw material were exchanged over the greatest distances (Rolett 1998). The Keqiutou adzes are not as finely chipped or finished as those from Huangguashan and Xitou, but they are of interest because Keqiutou is the earliest coastal Neolithic site in Fujian, dating to 5500–6500 B.P. (Jiao et al. 2004; Lin 2005).

GEOLOGICAL SOURCING OF THE FUJIAN ADZES

Stone adzes bear the chemical signature of their geological source. This makes it possible, by means of compositional analyses, to determine if two artifacts are made of rock from the same or different sources. With a large collection of adzes, it may be feasible to identify different source groups and the number of adzes that can be attributed to each source. Identifying the actual location of a prehistorically exploited source requires reference data for geological samples from known proveniences. Chemical reference data are essential to distinguish among the compositions of distinct geological units, and they also show the variability within individual formations. Often, however, as is the case with this study, published geochemical data for the research area are limited. If the published data are insufficient, it may not be possible to source the adzes to specific locations, although it may be feasible to narrow the range of possibilities or to identify the most likely place of origin.

We address this problem through an interdisciplinary approach. Our project includes geological surveys guided by the results of this pilot study. Samples collected during the surveys are analyzed at the Chinese Academy of Sciences Institute of Geology and Geophysics and the University of Hawai‘i Department of Geology and Geophysics, in the same laboratories where the adzes are studied. The goal of these ongoing surveys is to generate baseline geochemical data needed to identify specific locations or broader regions where the archaeologically recovered adzes were manufactured.

Our sourcing analyses are designed to determine the presence of imported stone adzes. If, as we believe, observed frequencies of imported artifacts reflect general levels of long-distance interaction, then the sourcing analyses provide a quantitative method for measuring access to nonlocal materials. The value of this information is that it represents empirical data for modeling long-term changes in the Neolithic interaction networks of southeast China.

Southeast China's coastal provinces of Zhejiang, Fujian, and Guangdong are part of a single geologically distinct region that also includes Taiwan and the Penghu Islands. Taiwan lies on the active margin of the Eurasian Plate, and it was formed—beginning around 5 mya—by the collision of this plate with the Philippine Sea Plate (Angelier 1990). Taiwan's landscape is marked by high mountain ranges composed primarily of metamorphic rocks, while volcanic rocks such as basalt and andesite are highly limited in distribution. By contrast, the Penghu Islands, which were formed by subduction zone magmatism, are entirely volcanic. The mainland setting is dominated by granite, sedimentary, and meta-

TABLE 1. THE FUJIAN ADZES: VOLCANIC ROCK TYPES REPRESENTED

ADZES	SITE TIME PERIOD	KEQIUTOU 5500–6500 B.P.	XITOU 4300–5000 B.P.	HUANGGUASHAN 3500–4300 B.P.	TOTAL
Basalt		2	—	—	2
Andesite		2	6	20	28
Dacite		—	4	4	8
Total adzes		4	10	24	38

morphic rocks. Areas of Cenozoic volcanic activity are associated with faults caused by continental extension, a process related to tectonic plate subduction (Zou et al. 2000). There are three of these faults in Fujian, one lying directly on the coast and two situated inland. Their orientation is parallel to the coastline. The volcanic rock consists mainly of dacite but also includes large outcrops of andesite. Outcrops of basalt are highly localized and they cover a much smaller area than other volcanic formations. Locations of the major andesite and basalt formations are plotted in Figure 1.

METHODS AND RESULTS

Our study analyzes 38 adzes from the Huangguashan, Xitou, and Keqiutou archaeological sites (Table 1). Based on hand inspection of the artifact assemblages, specimens selected for this study are representative in style and material of the adzes from these three sites. The specimens were sampled by removing around 20 g of rock to obtain material for petrographic examination, as well as analysis by XRF and ICP-MS (Table 2). We also analyzed 24 geological samples collected from three separate locations in Fujian (Table 3). All of these specimens consist of dense, fine-grained rock of the kind that was sought for adze manufacturing. Whole-rock major oxide abundances were analyzed using a Phillips PW2400 sequential X-ray fluorescence spectrometer at the Chinese Academy of Sciences. The analytical precision was better than 2 percent relative. Trace element concentrations were analyzed by ICP-MS at both the Chinese Academy of Sciences and the University of Hawai'i.

All 38 adzes are made of volcanic rock. The chemical composition of volcanic rock can alter through weathering, so in preparing our adze samples we removed the exterior cortex and used only the fresh, unaltered rock for analysis. The adzes can be differentiated on the basis of chemical composition as basalts, andesites, and dacites. Basalts are defined as rocks with <53 wt percent SiO_2 (calculated on a volatile-free basis); andesites are rocks with 53 to 63 percent SiO_2; dacites contain 63 to 70 percent SiO_2. The chemical composition of volcanic rocks differs according to the source of the magma and its evolutionary history. Although the chemical composition of different magma sources and their evolutionary paths vary by gradation along a continuum, the basic criteria discussed above are useful for making broad distinctions. Based on the chemical criteria, as well as petrographic examination, 2 of the adzes are made of basalt, 28 are made of andesite, and 8 are made of dacite (Table 1).

TABLE 2. GEOCHEMICAL COMPOSITIONAL DATA FOR ADZES FROM FUJIAN (CHINA)

	HUANGGUASHAN							
SAMPLE NO.:	H-1	H-2	H-3	H-4	H-5	H-6	H-7	H-8
SiO_2	63.06	62.07	67.31	61.35	61.16	62.21	58.86	58.45
TiO_2	0.67	0.63	0.65	0.64	0.67	0.69	0.62	0.65
Al_2O_3	15.42	14.77	14.27	15.47	17.05	16.32	15.73	16.94
Fe_2O_3	5.28	5.37	4.61	5.56	6.04	6.11	5.81	5.96
FeO								
MnO	0.12	0.09	0.15	0.10	0.12	0.13	0.10	0.08
MgO	2.85	3.77	2.45	3.71	2.47	2.56	4.25	3.82
CaO	7.81	8.32	6.39	7.89	8.04	6.27	9.24	7.61
Na_2O	0.96	0.99	0.92	0.92	0.45	1.64	0.77	1.61
K_2O	3.64	3.87	3.11	4.21	3.86	3.88	4.49	4.72
P_2O_5	0.20	0.15	0.17	0.16	0.18	0.20	0.16	0.19
SUM	100.01	100.02	100.02	100.02	100.03	100.02	100.02	100.03
Li	36	37	28	27	25	37	31	38
Be	2	2	2	2	2	3	3	3
Sc	12	13	11	13	11	14	14	17
V	84	89	85	96	94	93	114	110
Cr	886	894	1022	1291	1257	1027	971	873
Co	19	20	22	22	22	17	23	24
Ni	345	346	377	494	488	393	393	352
Cu	36	38	39	47	47	53	55	30
Zn	99	97	143	110	111	116	115	136
Ga	18	17	16	16	16	21	18	20
Rb	166	165	146	155	156	161	167	275
Sr	426	429	155	348	358	529	485	251
Y	26	26	26	24	24	26	27	29
Zr	126	130	144	121	124	136	140	136
Nb	14	14	15	14	14	16	15	15
Cs	18	19	11	8	9	36	14	31
Ba	434	430	457	392	402	729	457	460
La	38	38	35	33	36	42	37	39
Ce	73	73	73	67	68	86	72	77
Pr	9	9	8	8	8	10	8	9
Nd	32	32	30	29	30	37	32	35
Sm	6	6	6	6	6	7	6	7
Eu	1	1	1	1	1	1	1	1
Gd	6	6	5	5	5	6	6	6
Tb	1	1	1	1	1	1	1	1
Dy	5	5	5	5	5	5	5	6
Ho	1	1	1	1	1	1	1	1
Er	3	3	3	3	3	3	3	3
Tm	0	0	0	0	0	0	0	1
Yb	3	3	3	3	3	3	3	3
Lu	0	0	0	0	0	0	0	0
Hf	4	4	4	4	4	4	4	4
Ta	1	1	1	1	1	1	1	1
Tl	1	1	1	2	2	1	1	2
Pb	38	39	42	62	60	28	28	17
Bi	0	0	0	1	1	0	1	0
Th	14	14	13	14	14	16	15	16
U	3	3	3	2	2	8	5	3

TABLE 2 *(Continued)*

	HUANGGUASHAN							
SAMPLE NO.:	H-9	H-10	H-11	H-12	H-13	H-14	H-15	H-16
SiO_2	62.17	60.50	62.69	59.20	60.06	57.33	66.89	59.60
TiO_2	0.67	0.61	0.65	0.69	0.64	0.63	0.71	0.62
Al_2O_3	16.72	16.01	16.50	17.86	18.10	17.23	15.37	16.58
Fe_2O_3	6.02	5.28	5.89	5.09	5.84	8.51	4.94	5.10
FeO								
MnO	0.12	0.08	0.12	0.12	0.10	0.15	0.10	0.10
MgO	2.67	3.49	2.54	2.94	3.10	3.04	2.06	3.34
CaO	7.05	8.28	7.31	6.81	7.33	9.83	6.27	8.40
Na_2O	1.12	0.78	1.04	1.92	0.70	1.12	1.26	1.10
K_2O	3.29	4.81	3.08	5.16	3.99	2.01	2.25	5.04
P_2O_5	0.20	0.17	0.19	0.21	0.15	0.17	0.18	0.16
SUM	100.03	100.01	100.01	100.01	100.02	100.01	100.02	100.03
Li	35	22	23	15	14	15	30	17
Be	3	3	3	3	3	3	3	3
Sc	13	12	14	14	18	18	10	15
V	91	100	100	106	113	111	85	116
Cr	1022	822	813	900	920	913	790	930
Co	16	22	21	21	28	30	21	23
Ni	390	331	329	369	377	378	293	381
Cu	56	18	18	44	40	42	16	46
Zn	113	87	87	80	91	90	59	87
Ga	20	20	19	19	21	20	19	20
Rb	160	125	113	222	210	211	72	218
Sr	526	251	261	312	323	334	190	308
Y	26	28	29	31	33	29	23	29
Zr	139	145	151	141	152	134	155	136
Nb	15	13	15	14	18	16	14	14
Cs	33	3	3	16	15	15	1	16
Ba	739	743	741	489	476	480	598	470
La	43	37	39	41	41	39	42	38
Ce	88	73	77	81	82	79	83	76
Pr	10	9	9	11	12	11	9	9
Nd	37	30	35	35	36	35	35	34
Sm	7	6	7	7	7	7	6	7
Eu	2	1	1	1	1	1	1	1
Gd	6	6	6	6	6	6	5	6
Tb	1	1	1	1	1	1	1	1
Dy	5	5	5	5	5	5	4	5
Ho	1	1	1	1	1	1	1	1
Er	3	3	3	3	3	3	2	3
Tm	1	1	0	0	0	0	0	1
Yb	3	3	3	3	3	3	3	3
Lu	0	1	0	0	4	4	0	0
Hf	4	6	5	4	5	5	5	5
Ta	1	1	1	1	2	1	1	1
Tl	1	1	1	1	1	1	1	1
Pb	29	13	12	26	26	26	11	24
Bi	0	0	0	0	1	1	0	0
Th	15	16	15	17	17	17	16	16
U	9	3	3	7	7	8	3	7

Table 2 *(Continued)*

	HUANGGUASHAN							
SAMPLE NO.:	H-17	H-18	H-19	H-20	H-21	H-22	H-23	H-24
SiO_2	59.91	61.55	58.10	62.83	55.43	57.86	59.28	63.50
TiO_2	0.61	0.62	0.61	0.67	0.59	0.65	0.61	0.65
Al_2O_3	15.80	16.54	16.12	17.19	16.05	16.78	16.97	14.06
Fe_2O_3	5.34	5.99	5.79	5.37	6.02	7.28	7.13	4.80
FeO								
MnO	0.10	0.09	0.11	0.08	0.16	0.11	0.11	0.15
MgO	5.23	2.66	4.05	2.55	3.99	3.29	2.59	3.11
CaO	8.53	6.70	9.96	6.27	12.31	9.32	7.83	8.59
Na_2O	0.45	0.73	0.79	1.68	0.88	0.26	0.70	1.47
K_2O	3.91	4.95	4.33	3.17	4.42	4.30	4.65	3.50
P_2O_5	0.13	0.16	0.16	0.21	0.17	0.17	0.15	0.16
SUM	100.02	100.00	100.02	100.02	100.04	100.03	100.03	100.00
Li	19	28	25	26	27	8	27	37
Be	3	3	3	3	2	2	3	2
Sc	15	15	15	13	15	16	15	11
V	105	88	103	92	105	106	103	86
Cr	739	648	1067	1008	1059	856	1070	884
Co	20	18	23	16	25	18	23	19
Ni	306	245	422	367	434	315	432	344
Cu	48	20	29	21	30	17	27	36
Zn	103	86	101	75	104	103	130	96
Ga	18	18	19	18	21	21	20	19
Rb	159	104	168	76	156	180	209	166
Sr	358	136	486	181	488	213	228	430
Y	27	27	27	29	27	28	28	25
Zr	135	150	137	138	140	140	151	136
Nb	13	14	14	15	16	14	14	15
Cs	16	8	19	16	18	16	17	20
Ba	441	679	536	701	526	444	590	436
La	35	32	39	33	38	41	38	39
Ce	68	73	75	70	74	78	76	75
Pr	8	8	9	8	9	9	9	9
Nd	31	29	34	30	32	34	34	32
Sm	6	6	6	6	6	7	6	6
Eu	1	1	1	1	1	1	1	1
Gd	6	5	6	6	5	6	6	6
Tb	1	1	1	1	1	1	1	1
Dy	5	5	5	6	5	5	5	5
Ho	1	1	1	1	1	1	1	1
Er	3	3	3	3	3	3	3	3
Tm	0	0	0	0	0	0	0	0
Yb	3	3	3	3	3	3	3	3
Lu	0	0	0	0	0	0	0	0
Hf	4	4	4	5	5	4	5	4
Ta	1	1	1	1	1	1	1	1
Tl	1	1	1	1	1	1	2	1
Pb	26	34	27	11	28	55	36	37
Bi	0	0	0	0	0	1	0	0
Th	14	13	15	15	16	16	15	17
U	2	2	4	2	4	3	3	4

TABLE 2 *(Continued)*

	XITOU							
SAMPLE NO.:	X-1	X-2	X-3	X-4	X-5	X-6	X-7	X-8
SiO_2	64.98	64.83	59.24	59.50	62.54	66.38	62.29	64.21
TiO_2	0.69	0.71	0.61	0.61	0.62	0.63	0.69	0.67
Al_2O_3	16.81	16.18	16.19	16.09	15.43	16.36	16.43	16.95
Fe_2O_3	5.25	5.73	6.16	5.91	4.57	4.86	5.43	5.68
FeO								
MnO	0.10	0.07	0.13	0.11	0.09	0.11	0.08	0.09
MgO	2.14	2.66	3.81	3.86	2.70	1.99	2.24	2.18
CaO	5.09	5.06	8.42	8.85	7.26	5.67	7.33	5.59
Na_2O	1.60	1.25	0.58	0.67	1.98	1.31	0.40	0.69
K_2O	3.20	3.31	4.75	4.28	4.60	2.51	4.91	3.70
P_2O_5	0.16	0.24	0.14	0.14	0.25	0.18	0.18	0.21
SUM	100.03	100.03	100.03	100.02	100.03	100.01	99.99	99.99
Li	31	53	37	13	98	31	22	51
Be	3	3	2	3	3	3	3	3
Sc	15	14	11	15	14	13	16	15
V	97	112	86	100	96	90	101	101
Cr	707	888	884	955	1028	698	1644	1340
Co	11	19	19	22	16	10	25	19
Ni	271	358	344	367	410	267	580	510
Cu	15	16	36	20	19	13	58	22
Zn	65	99	96	84	79	66	103	91
Ga	18	19	19	20	18	19	21	19
Rb	145	113	166	193	202	156	172	178
Sr	197	190	430	359	309	190	194	164
Y	31	27	25	29	36	35	28	31
Zr	141	147	136	139	120	158	135	145
Nb	16	15	15	15	16	16	16	16
Cs	26	3	20	15	20	28	10	27
Ba	566	532	436	412	502	600	594	510
La	39	34	39	37	36	41	42	42
Ce	81	70	75	74	73	82	81	83
Pr	9	8	9	9	9	10	10	10
Nd	33	32	32	33	34	37	37	37
Sm	7	6	6	6	7	8	7	7
Eu	1	1	1	1	1	1	1	1
Gd	6	6	6	6	7	7	6	6
Tb	1	1	1	1	1	1	1	1
Dy	6	5	5	5	7	6	6	6
Ho	1	1	1	1	1	1	1	1
Er	3	3	3	3	4	4	3	3
Tm	1	0	0	0	1	1	0	1
Yb	3	3	3	3	4	4	3	3
Lu	1	0	0	0	1	1	0	1
Hf	4	4	4	4	4	4	4	4
Ta	1	1	1	1	1	1	1	1
Tl	2	1	1	1	1	2	1	1
Pb	20	19	37	14	16	23	60	14
Bi	0	0	0	0	0	0	1	0
Th	16	13	17	17	15	16	16	16
U	3	2	4	4	3	3	3	3

TABLE 2 *(Continued)*

	XITOU		KEQIUTOU			
SAMPLE NO.:	X-9	X-10	K-1	K-2	K-3	K-4
SiO_2	60.03	62.06	60.92	51.68	51.00	55.14
TiO_2	0.62	0.63	1.06	1.07	1.24	0.97
Al_2O_3	15.87	14.73	17.06	18.55	16.46	18.53
Fe_2O_3	5.93	6.15	8.72	10.95	10.94	8.93
FeO						
MnO	0.11	0.11	0.14	0.17	0.33	0.15
MgO	3.43	2.71	1.69	4.99	9.60	3.74
CaO	9.07	9.05	6.01	8.58	8.25	9.36
Na_2O	0.37	0.57	3.33	2.37	1.98	2.12
K_2O	4.43	3.84	0.80	1.34	0.04	0.89
P_2O_5	0.14	0.15	0.28	0.32	0.19	0.19
SUM	100.00	100.01	100.00	100.03	100.03	100.03
Li	16	6	31	28	54	63
Be	5	3	1	1	4	3
Sc	15	15	26	25	20	14
V	97	93	229	218	169	104
Cr	948	3609	1340	1310	2963	2952
Co	21	42	40	38	38	37
Ni	365	1257	506	499	1183	1059
Cu	21	53	52	50	50	79
Zn	88	121	113	112	130	133
Ga	18	20	18	19	19	20
Rb	200	148	38	39	120	193
Sr	364	332	696	695	531	350
Y	30	29	18	16	20	26
Zr	145	120	94	83	101	125
Nb	16	19	7	6	12	19
Cs	17	8	2	2	12	18
Ba	415	745	574	627	596	534
La	39	49	16	13	28	39
Ce	79	90	32	30	57	76
Pr	9	10	4	4	7	8
Nd	37	38	18	18	24	30
Sm	7	7	4	4	5	6
Eu	1	1	1	1	1	1
Gd	6	6	4	4	5	6
Tb	1	1	1	1	1	1
Dy	5	5	3	3	4	5
Ho	1	1	1	1	1	1
Er	3	3	2	2	2	3
Tm	0	0	0	0	0	0
Yb	3	3	2	2	2	3
Lu	0	0	0	0	0	0
Hf	4	4	2	2	3	4
Ta	1	1	1	1	1	1
Tl	1	1	0	0	1	1
Pb	13	26	7	7	30	54
Bi	0	1	0	0	0	0
Th	17	16	2	2	9	16
U	5	3	0	1	3	6

TABLE 3. GEOCHEMICAL COMPOSITIONAL DATA FOR GEOLOGICAL SAMPLES FROM FUJIAN (CHINA)

SAMPLE NO.:	HUANGGUASHAN								
ROCK TYPE (1):	HG-1 Bs	HG-2 Dc	HG-3 Dc	HG-4 Dc	HG-5 Dc	HG-6 Dc	HG-7 Dc	HG-8 Dc	HG-9 Dc
SiO_2	52.97	68.83	65.50	67.62	73.11	68.96	65.24	66.90	67.17
TiO_2	1.55	0.59	0.56	0.59	0.45	0.55	0.64	0.74	0.54
Al_2O_3	15.19	14.67	15.16	14.45	12.62	13.43	14.73	14.83	14.22
Fe_2O_3	10.86	4.12	4.79	4.98	3.97	4.11	5.47	5.12	4.51
MnO	0.148	0.090	0.097	0.085	0.180	0.119	0.139	0.083	0.099
MgO	4.99	2.18	2.24	2.40	1.70	1.79	1.55	2.29	2.04
CaO	8.75	3.10	4.86	3.58	4.72	4.48	7.34	3.60	4.90
Na_2O	2.48	0.88	1.56	1.85	1.79	2.37	1.43	1.55	2.15
K_2O	2.41	5.41	5.05	4.26	1.35	4.02	3.23	4.65	4.19
P_2O_5	0.650	0.136	0.197	0.176	0.122	0.176	0.221	0.234	0.184
SUM	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
LOI									
Li	—	—	—	126	28	28	4	20	—
Be	—	—	—	3	2	3	2	3	—
Sc	—	—	—	13	8	12	14	13	—
V	—	—	—	88	48	83	86	104	—
Cr	—	—	—	1516	901	782	784	1199	—
Co	—	—	—	19	14	15	19	21	—
Ni	—	—	—	516	331	281	302	456	—
Cu	—	—	—	54	31	21	17	20	—
Zn	—	—	—	95	135	98	105	82	—
Ga	—	—	—	20	16	19	17	18	—
Rb	—	—	—	263	94	178	215	145	—
Sr	—	—	—	253	188	249	255	314	—
Y	—	—	—	26	27	26	25	26	—
Zr	—	—	—	159	156	151	155	181	—
Nb	—	—	—	16	15	14	13	15	—
Cs	—	—	—	74	6	75	11	4	—
Ba	—	—	—	507	859	479	635	675	—
Mn	—	—	—	—	—	—	—	—	—
La	—	—	—	46	45	35	32	38	—
Ce	—	—	—	91	84	70	66	71	—
Pr	—	—	—	10	10	8	8	9	—
Nd	—	—	—	38	35	31	31	32	—
Sm	—	—	—	7	6	6	6	6	—
Eu	—	—	—	1	1	1	1	1	—
Gd	—	—	—	6	5	6	5	5	—
Tb	—	—	—	1	1	1	1	1	—
Dy	—	—	—	5	5	5	5	5	—
Ho	—	—	—	1	1	1	1	1	—
Er	—	—	—	3	3	3	3	3	—
Tm	—	—	—	0	0	0	0	0	—
Yb	—	—	—	3	3	3	3	3	—
Lu	—	—	—	0	0	0	0	0	—
Hf	—	—	—	5	5	4	5	5	—
Ta	—	—	—	1	1	1	1	1	—
Tl	—	—	—	2	1	1	1	1	—
Pb	—	—	—	27	33	22	29	28	—
Bi	—	—	—	0	1	0	0	0	—
Th	—	—	—	20	23	17	18	19	—
U	—	—	—	4	4	3	4	4	—

1. Abbreviations: An, andesite; Bs, basalt; Dc, dacite; Rh, rhyolite.

TABLE 3 *(Continued)*

SAMPLE NO.:	LONGHAI AND ZHANGPU					MINHOU			
ROCK TYPE (1):	FUJ-2 Bs	FUJ-5 An	FUJ-6 Bs	FUJ-13 Bs	FUJ-15 Bs	FUJ-33 An	FUJ-35 Dc	FUJ-36 An	FUJ-37 An
SiO_2	52.05	54.67	50.18	52.11	51.52	57.51	65.00	61.84	55.15
TiO_2	2.05	1.30	2.28	1.70	2.59	0.75	0.75	0.72	0.75
Al_2O_3	15.12	15.55	16.06	15.22	15.33	17.71	16.52	16.01	17.11
Fe_2O_3	11.04	10.12	11.42	10.98	11.90	6.49	6.37	6.73	6.68
MnO	0.14	0.13	0.12	0.13	0.13	0.10	0.07	0.10	0.24
MgO	6.70	6.91	6.47	6.98	6.00	3.42	2.54	3.28	4.48
CaO	8.18	9.31	7.63	8.56	8.09	8.40	2.13	6.11	10.43
Na_2O	2.64	2.32	3.52	2.52	2.98	1.13	3.37	1.60	2.78
K_2O	1.59	0.52	2.49	1.43	1.50	4.09	2.67	3.05	2.15
P_2O_5	0.44	0.15	0.62	0.32	0.59	0.20	0.20	0.20	0.24
SUM	99.93	100.95	100.76	99.95	100.62	99.78	99.60	99.62	99.99
LOI	0.50	0.45	1.27	0.24	0.74	1.06	1.48	2.27	1.80
Li	—	—	—	—	—	—	—	—	—
Be	—	—	—	—	—	—	—	—	—
Sc	20	23	14	22	18	17	15	13	12
V	158	138	150	156	163	110	158	107	130
Cr	236	260	116	246	175	84	36	57	36
Co	57	45	43	54	43	25	20	19	29
Ni	195	154	114	164	127	49	33	37	27
Cu	—	—	—	—	—	—	—	—	—
Zn	112	92	147	116	141	114	99	118	111
Ga	—	—	—	—	—	—	—	—	—
Rb	33	15	64	28	30	193	115	119	166
Sr	475	233	677	389	543	229	411	272	444
Y	21	14	18	19	24	35	25	30	24
Zr	248	88	301	201	273	172	190	173	208
Nb	33	14	71	29	41	16	12	15	12
Cs	—	—	—	—	—	—	—	—	—
Ba	324	167	609	260	328	640	668	638	697
Mn	1121	1061	918	1068	1061	991	622	755	1312
La	—	—	—	—	—	—	—	—	—
Ce	—	—	—	—	—	—	—	—	—
Pr	—	—	—	—	—	—	—	—	—
Nd	—	—	—	—	—	—	—	—	—
Sm	—	—	—	—	—	—	—	—	—
Eu	—	—	—	—	—	—	—	—	—
Gd	—	—	—	—	—	—	—	—	—
Tb	—	—	—	—	—	—	—	—	—
Dy	—	—	—	—	—	—	—	—	—
Ho	—	—	—	—	—	—	—	—	—
Er	—	—	—	—	—	—	—	—	—
Tm	—	—	—	—	—	—	—	—	—
Yb	—	—	—	—	—	—	—	—	—
Lu	—	—	—	—	—	—	—	—	—
Hf	—	—	—	—	—	—	—	—	—
Ta	—	—	—	—	—	—	—	—	—
Tl	—	—	—	—	—	—	—	—	—
Pb	−2	−2	2	−2	−2	30	28	25	53
Bi	—	—	—	—	—	—	—	—	—
Th	2	−2	6	−2	2	16	14	14	17
U	−2	−2	−2	−2	−2	4	3	−2	5

TABLE 3 *(Continued)*

	DONGZHANG		CHANGLE		FUAN	
SAMPLE NO.:	FUJ-40	FUJ-42	FUJ-45	FUJ-46	FUJ-47	FUJ-50
ROCK TYPE (1):	An	An	Bs	Rh	Dc	Rh
SiO_2	54.63	56.59	45.54	75.30	63.31	77.50
TiO_2	1.11	1.05	1.06	0.33	0.76	0.08
Al_2O_3	18.49	17.92	17.65	13.24	16.26	12.43
Fe_2O_3	8.97	8.25	13.23	1.28	7.16	1.07
MnO	0.15	0.12	0.22	0.04	0.15	0.07
MgO	4.16	3.67	7.36	0.28	2.47	0.01
CaO	8.01	7.62	11.10	0.95	4.17	0.45
Na_2O	3.26	2.86	1.95	3.54	3.64	3.84
K_2O	1.16	1.98	1.79	4.66	1.79	4.56
P_2O_5	0.44	0.40	0.38	0.15	0.36	0.07
SUM	100.36	100.46	100.24	99.76	100.05	100.06
LOI	2.32	1.52	1.39	0.62	0.89	0.50
Li	—	—	—	—	—	—
Be	—	—	—	—	—	—
Sc	19	17	42	4	16	4
V	203	186	354	8	115	−3
Cr	21	28	93	−3	−3	−3
Co	29	24	44	17	26	24
Ni	29	29	23	9	12	13
Cu	—	—	—	—	—	—
Zn	112	102	171	35	112	58
Ga	—	—	—	—	—	—
Rb	36	48	69	114	99	245
Sr	840	818	646	193	532	8
Y	16	15	16	28	19	44
Zr	125	133	74	239	145	134
Nb	7	8	4	14	8	33
Cs	—	—	—	—	—	—
Ba	567	623		1229	658	−11
Mn	1209	1008	1691	327	1335	628
La	—	—	—	—	—	—
Ce	—	—	—	—	—	—
Pr	—	—	—	—	—	—
Nd	—	—	—	—	—	—
Sm	—	—	—	—	—	—
Eu	—	—	—	—	—	—
Gd	—	—	—	—	—	—
Tb	—	—	—	—	—	—
Dy	—	—	—	—	—	—
Ho	—	—	—	—	—	—
Er	—	—	—	—	—	—
Tm	—	—	—	—	—	—
Yb	—	—	—	—	—	—
Lu	—	—	—	—	—	—
Hf	—	—	—	—	—	—
Ta	—	—	—	—	—	—
Tl	—	—	—	—	—	—
Pb	10	11	10	19	19	29
Bi	—	—	—	—	—	—
Th	6	5	2	13	5	22
U	−2	−2	−2	2	−2	6

Basalts

The two basalt adzes are both from Keqiutou. Basalts can be subdivided into two groups called alkalic and subalkalic. This distinction is made using the variation of the alkali oxides Na_2O and K_2O versus SiO_2 (Macdonald and Katsura 1964). Both of the Keqiutou adzes are made of subalkalic basalt. The only large source of subalkalic basalt on the Fujian coast is in the vicinity of Longhai and Zhangpu, an area located south of Keqiutou (Yu 1989; Zou et al. 2000) (Fig. 1). Basalt outcrops in this region date to around 16 to 19 mya (Chen and Zhang 1992). The best documented outcrops are at Niutoushan, an area displaying prominent sea cliffs of fine-grained subalkalic basalt (Chen and Zhang 1992; Lin 1992; Wang et al. 1991; Yu 1989). In appearance, these formations closely resemble the Penghu archipelago sea cliffs that supplied basalt for the massive adze workshops on Qimei Island (Rolett et al. in press). Both the Qimei and Niutoushan sea cliffs are characterized by columnar jointing caused by rapid cooling of the lava flow (Wang et al. 1991). The rock cleaves naturally into angular blocks, many of which have fallen from the fracturing cliff face and lie piled on the slopes and boulder beaches below, providing a readily available supply of fine-grained basalt. There is no known evidence, however, for Neolithic tool production at Niutoushan. We collected and analyzed five samples of basalt and andesite from the area in and around Niutoushan. We also found alkalic basalt in Changle, represented by sample FUJ-45.

Volcanic dikes, found along much of the Fujian coast, provide another source of basalt (Li 1994:132–133). These dikes are mostly undocumented, however, so their frequency and distribution is difficult to determine. Dikes intruding into the coastal formations of granite stand out because the black volcanic rock contrasts sharply with the white granite. Apart from coastal lava flows and volcanic dikes, Fujian's only other basalt formations lie deep in the province's mountainous interior. Subalkalic basalts are unknown from the inland locations. Beyond Fujian, the nearest source of subalkalic basalts is the Penghu Islands (Juang and Chen 1999; Li 1994). A much more distant, larger exposure of coastal basalts lies on Hainan Island and the neighboring Leizhou Peninsula of Guangdong Province. These outcrops consist mainly of subalkalic basalts but also include alkalic basalts (Ho et al. 2000).

Chemical compositions of the Keqiutou adzes can be compared with published data for geological samples from Fujian, Penghu, Hainan, and the Leizhou Peninsula (Guangdong). The best-documented area is Penghu, with data for 120 geological samples collected from almost every island in the archipelago (Li 1994), in addition to data for 31 artifacts and geological samples collected at the Qimei adze workshops (Rolett et al. in press). Data for the other areas are scarce.

Concentrations of the trace elements Ba, Sr, and Rb are particularly significant for identifying the possible sources of the Keqiutou basalt adzes. Although Ba, Sr, and Rb are water-soluble incompatible elements and their concentrations can change during weathering and alteration, this possible source of variation is virtually eliminated by the fact that our archaeological and geological samples consist only of fresh rock. Barium values for the Keqiutou adzes (596 and 627 ppm) fall well outside the range of variation recorded for Niutoushan and Penghu subalkalic basalts. Only the Fujian volcanic dikes have Ba contents comparable to the

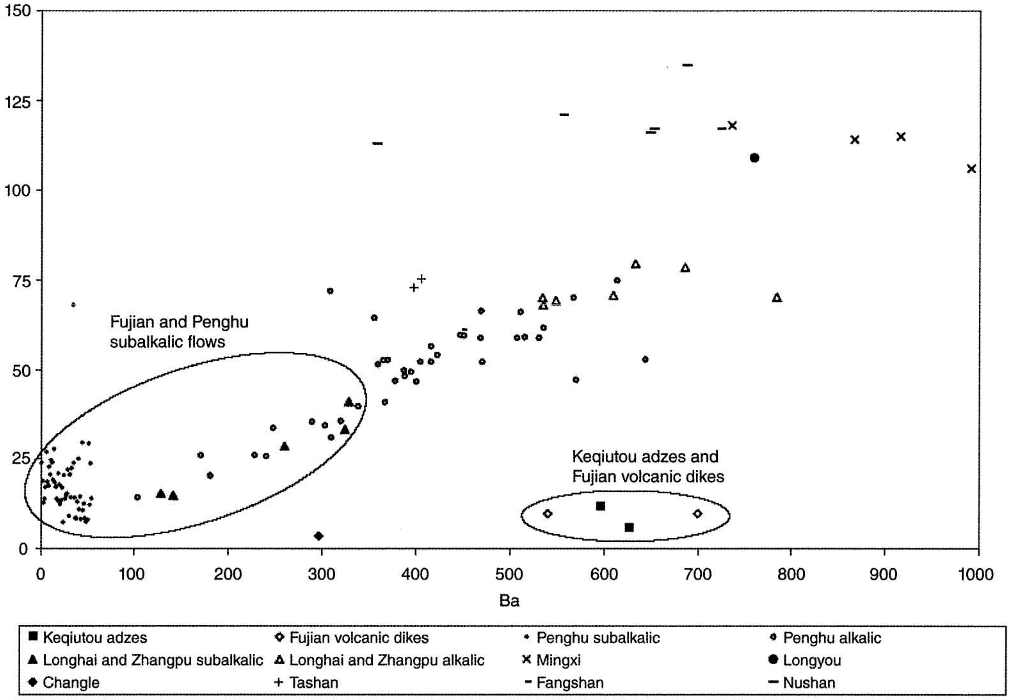

Fig. 2. Nb and Ba for basalt adzes and geological samples from Fujian (China) and the Penghu Islands.

artifacts (Fig. 2). Sr values (531 and 695 ppm) for the adzes are also higher than those for the Niutoushan and Penghu subalkalic basalts and most similar to the dike samples (Table 4). Finally, the artifacts stand out among the subalkalic basalts in terms of their high Rb contents, although there are no published Rb data for the volcanic dikes. The Keqiutou adzes are chemically distinct from all of the basalts studied from Penghu, as is illustrated by Figure 2. Our results suggest that the Keqiutou adzes are made of Fujian rock rather than Penghu Islands basalt. There is no perfect match, however, with any of the published data for Fujian. It is not likely that the adzes derive from a mainland source located outside Fujian because the only other known basalts are on Hainan Island and the Leizhou Peninsula some 1100 km to the south.

Andesites

Andesite is the most common rock type among the adzes selected for this study. Because andesite is rare in Penghu, these islands are probably not the source for andesite adzes found in Fujian. By contrast, andesite is abundant in areas close to the Xitou site and in other parts of Fujian. We collected and analyzed three andesite samples from formations in Minhou, near Xitou. These andesite flows are well mapped, but our results provide the first geochemical data for this area. In addition, we collected three andesite samples from Dongzhang and Zhangpu.

Table 4. Basalt Adzes from Keqiutou Compared with Fujian and Penghu Islands Geological Samples

	FUJIAN KEQIUTOU ADZES		FUJIAN VOLCANIC DIKES (1)		FUJIAN LONGHAI AND ZHANGPU (2)		FUJIAN LONGHAI AND ZHANGPU (3)		PENGHU ISLANDS LAVA FLOWS (4)	
	K-2	K-3	KS02	MS02	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
SiO_2	51.68	51.00	53.33	53.31	50.32	49.36–51.74	51.46	50.18–52.11	50.60	48.1–53.37
TiO_2	1.07	1.24	1.56	0.96	1.27	0.96–1.50	2.16	1.70–2.59	2.02	1.67–2.59
Al_2O_3	18.55	16.46	16.04	17.10	16.18	14.91–17.73	15.43	15.12–16.06	14.33	13.2–15.74
Fe_2O_3	10.95	10.94	10.80	8.41			11.33	10.98–11.90	11.48	10.15–14.88
MnO	0.17	0.33	0.23	0.10	0.13	0.02–0.22	0.13	0.12–0.13	0.15	0.11–0.25
MgO	4.99	9.60	4.86	6.00	7.42	6.16–9.51	6.54	6.00–6.98	7.24	5.52–9.04
CaO	8.58	8.25	7.71	8.88	9.29	8.53–10.17	8.11	7.63–8.56	9.22	8.48–10.1
Na_2O	2.37	1.98	4.33	2.87	2.75	2.51–3.17	2.91	2.52–3.52	2.92	1.74–3.42
K_2O	1.34	0.04	1.46	1.92	0.46	0.31–0.78	1.75	1.43–2.49	0.51	0.2–1.07
P_2O_5	0.32	0.19	0.50	0.42	0.19	0.10–0.28	0.49	0.32–0.62	0.28	0.17–0.45
SUM	100.03	100.03	100.82	99.97	98.39	96.77–100.07	100.31	99.93–100.76		
Rb	39	120	—	—	8	41–14	—		11.8	2.1–49
Sr	695	531	603	705	290	246–313	—		310.0	203.5–405.1
Nb	6	12	10	10	15	15–15	—		17.7	7.5–68
Ba	627	596	540	700	135	128–141	—		141.8	68.4–253.4
Sm	4	5	7	8	3	3	—		—	

1. Li 1994.
2. Subalkalic basalts from Yu 1989 and Zou 2000. Rb and Sr averages and ranges based on 7 samples. Data for other elements based on 2 samples (Zou 2000).
3. Data from Table 3 this paper.
4. Subalkalic basalts. Data based on 54 samples (Li 1994).

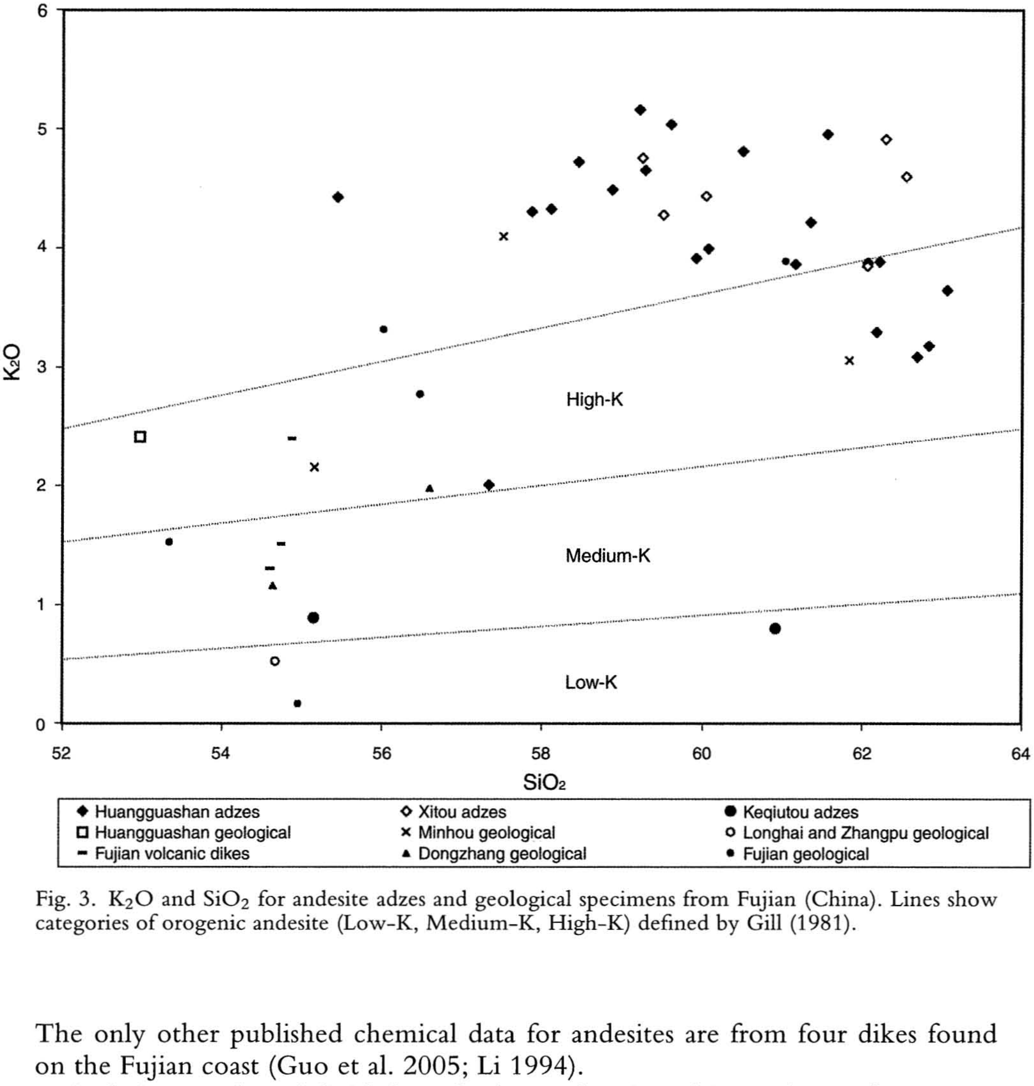

Fig. 3. K_2O and SiO_2 for andesite adzes and geological specimens from Fujian (China). Lines show categories of orogenic andesite (Low-K, Medium-K, High-K) defined by Gill (1981).

The only other published chemical data for andesites are from four dikes found on the Fujian coast (Guo et al. 2005; Li 1994).

Andesites can be subdivided on the basis of K_2O and SiO_2 chemical composition. Most are classified as "orogenic andesite," a term defining andesites with $K_2O < (0.145 \times SiO_2 - 5.135)$ (Gill 1981: 2–7). Some 19 of the 28 andesite adzes contain K_2O concentrations that are higher than those of the orogenic andesites (Fig. 3). Our three geological samples of andesite from Minhou also fit this pattern of high K_2O versus SiO_2. Table 5 shows compositions of the andesite adzes in comparison with the average composition of orogenic andesite and data for the Fujian geological data. The Huangguashan and Xitou adzes also stand out because of their low concentrations of Na_2O and highly uniform concentrations of TiO_2.

The Keqiutou andesite adzes fall into the categories of Low-K and Med-K orogenic andesite, indicating they are made from kinds of raw material not present among the Huangguashan and Xitou assemblages. As shown in Figure 3, our single geological sample of andesite from the Longhai/Zhangpu region is a Low-

K orogenic andesite, suggesting this area as a possible source for some of the Keqiutou adzes. The two Dongzhang andesite samples are also a fairly close match with the Medium-K Keqiutou adze. Based on the available data, it appears that the Keqiutou andesite adzes, like the Keqiutou basalt adzes, probably derive from sources on the Fujian coast.

On current evidence, we hypothesize that the Huangguashan and Xitou andesite adzes derive from a single region, although we do not know if variability among the specimens represents multiple sources within one region or a large source with internal chemical variability. The distribution of andesite formations helps to narrow the range of possible sources. There are extensive andesite flows near Xitou, in the mountains south of the Min River, but andesite is scarce near Huangguashan and along the Fujian coast in general. Based on chemical similarity of the Minhou geological samples to the Huangguashan and Xitou adzes, the most likely source area is in the vicinity of the Min River.

Dacites

Eight of the adzes (four from Huangguashan and four from Xitou) are made of dacite, which is the most widely distributed volcanic rock in Fujian. Dacite is abundant near Huangguashan; eight of the nine geological specimens we collected near Huangguashan consist of this material. Compositions of the geological specimens are somewhat similar to those of the adzes, as illustrated by the plot of CaO versus SiO_2 (Fig. 4), which shows that both sets of samples fall into a single linear array. This suggests that the geological specimens and the adzes derive from a single magma series or group of magmas that are genetically related to each other. The Xitou dacite adzes also cluster in the same linear array.

There are two possible explanations. First, the overall similarities in composition may reflect broad similarities among the Fujian dacite formations. This interpretation is supported by our results for a single dacite geological sample from Minhou and another from Fuan. The Huangguashan and Xitou dacite adzes may have been manufactured locally, using naturally occuring rock from separate formations that we are unable to differentiate using our available major and trace element data. Another possibility is that the Huangguashan and Xitou dacite adzes are made of raw material from a single cluster of related geological formations, such as those near Huangguashan. We consider this hypothesis less likely. Our future research will test the alternative models by measuring the concentrations of radioactive isotopes such as $^{87}Sr/^{86}Sr$, which could reveal unique chemical signatures for dacites from different formations.

DISCUSSION

We studied representative stone adzes from three coastal Neolithic sites in southeast China ranging in age from 6500 to 3500 B.P. All of the adzes we sampled are made of volcanic rock. Our analyses show that a diverse selection of raw materials, including basalts, andesites, and dacites, was used in manufacturing the adzes. Most of the adzes are made of andesite, although dacite is the most widely distributed volcanic rock in Fujian. The diversity of their chemical compositions indicates the adzes are made of rock deriving from many different geological forma-

Table 5. Composition of the Fujian Andesite Adzes Compared with Geological Samples

	ANDESITE ADZES FROM FUJIAN ARCHAEOLOGICAL SITES				FUJIAN GEOLOGICAL SAMPLES								OROGENIC ANDESITE (3)
	HUANGGUASHAN	XITOU	KEQIUTOU		DONGZHANG		LONGHAI/ ZHANGPU	MINHOU (1)		DIKES (2)			
	AVERAGE	AVERAGE	K-1	K-4	FUJ-40	FUJ-42	FUJ-5	AVERAGE	RANGE	TH02	PC01	ZUD-02A	AVERAGE
n	*21*	*6*						*3*					*2500*
SiO_2	60.17	60.94	60.92	55.14	54.63	56.59	54.67	58.17	55.15–61.84	54.73	54.87	54.60	58.18
TiO_2	0.64	0.63	1.06	0.97	1.11	1.05	1.30	0.74	0.72–0.75	1.09	1.23	0.82	0.78
Al_2O_3	16.48	15.79	17.06	18.53	18.49	17.92	15.55	16.94	15.55–17.71	16.08	16.67	16.68	17.47
Fe_2O_3	5.94	5.69	8.72	8.93	8.97	8.25	10.12	6.63	6.49–6.73	9.98	9.23	8.76	3.13
FeO	—	—	—	—	—	—	—	—		—	—	—	4.34
MnO	0.11	0.11	0.14	0.15	0.15	0.12	0.13	0.15	0.10–0.24	0.14	0.12	0.12	0.15
MgO	3.28	3.12	1.69	3.74	4.16	3.67	6.91	3.72	3.28–4.48	6.23	4.90	6.66	3.64
CaO	8.15	8.33	6.01	9.36	8.01	7.62	9.31	8.31	6.11–10.43	6.65	7.53	8.94	7.27
Na_2O	0.98	0.76	3.33	2.12	3.26	2.86	2.32	1.84	1.13–2.78	3.32	3.04	2.80	3.23
K_2O	4.09	4.47	0.80	0.89	1.16	1.98	0.52	3.10	2.15–4.09	1.51	2.39	1.30	1.52
P_2O_5	0.17	0.17	0.28	0.19	0.44	0.40	0.15	0.21	0.20–0.24	0.38	0.73	0.33	0.21
SUM	100.02	100.01	100.00	100.03	100.36	100.46	100.95	99.80	99.62–99.99	100.12	100.70	101.01	99.92
Sc	14	14	26	14	19	17	—	—	—	—	—	—	—
V	101	96	229	104	203	186	—	—	—	—	—	—	—
Cr	951	1511	1340	2952	21	28	—	—	—	—	—	—	—
Co	21	24	40	37	29	24	—	—	—	—	—	—	—
Ni	376	554	506	1059	29	29	—	—	—	—	—	—	—
Zn	101	95	113	133	112	102	—	—	—	—	—	—	—
Rb	169	180	38	193	36	48	—	—	—	—	—	—	—
Sr	344	332	696	350	840	818	—	—	—	681	729	634	—
Y	28	30	18	26	16	15	—	—	—	—	—	—	—
Zr	138	133	94	125	125	133	—	—	—	—	—	—	—
Nb	15	16	7	19	7	8	—	—	—	5	15	6	—

Ba	541	517	574	534	567	623	—	—	—	371	881	520	—
La	38	40	16	39	—	—	—	—	—	20	35	29	—
Sm	6	7	4	6	—	—	—	—	—	5	7	6	—
Tb	1	1	1	1	—	—	—	—	—	1	1	1	—
Yb	3	3	2	3	—	—	—	—	—	2	2	2	—
Pb	31	28	7	54	10	11	—	—	—	—	—	—	—
Th	15	16	2	16	6	5	—	—	—	—	—	—	—
U	4	4	0	6	−2	−2	—	—	—	—	—	—	—

1. Data from Table 3 this paper.
2. Data from Li 1994.
3. Data from Gill 1981.

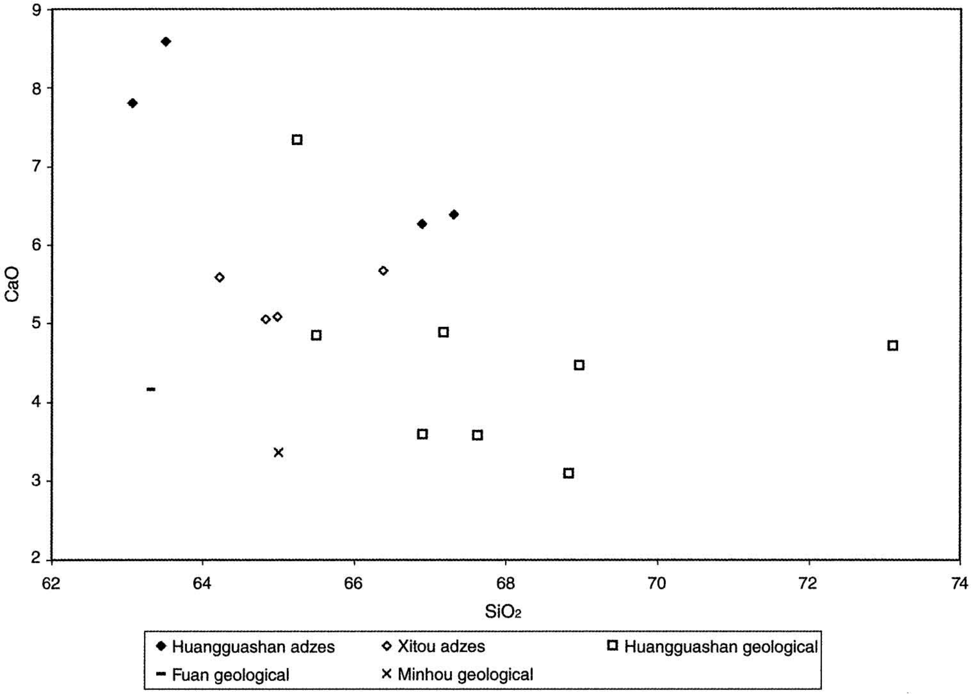

Fig. 4. SiO_2 and CaO for dacite adzes and geological specimens from Fujian (China).

tions. None of the adzes have identical chemical signatures. So far there is no evidence of specialized centers for adze production, such as those known for the Penghu Islands. Raw material for the adzes was likely taken from scattered locations or collected in the form of cobbles found in riverbeds. Some of the adzes were probably produced and used locally, while others were obtained through exchange networks.

We will refine these initial sourcing results by analyzing more archaeologically excavated adzes and through additional field surveys to provide better geological reference data. Both the Huangguashan and Xitou artifact assemblages include numerous andesite adzes, even though there are no known sources of this material near Huangguashan. We hypothesize that the Min River andesite flows could have supplied adzes for both Xitou and Huangguashan, as for example if people used rafts or canoes to transport adzes down the river and along the coast. We will test this hypothesis by continued surveying and sampling of the major andesite formations in order to identify their chemical signatures and to estimate compositional variability within and among them. Our new chemical analyses will include measurements of Sr and Pb isotopes produced by radioactive decay, which may be more sensitive than the major and trace elements for differentiating among different formations.

This study raises a number of questions. Huge workshops in the Penghu Islands supplied the Neolithic peoples of Taiwan with large numbers of adzes. Were these tools also carried to Mainland China? At this point, our analyses do not show evidence for the exchange of stone adzes between Penghu and the mainland, even though the Neolithic settlements of Huangguashan and Xitou were contemporaneous with the Penghu adze workshops. The two basalt adzes we identified are from Keqiutou, a site predating the Penghu centers for adze production. The Keqiutou adzes are made of subalkalic basalt, whereas the Penghu adzes mass-produced on Qimei are made of alkalic basalt (Rolett et al. 2000; Rolett et al. in press).

The lack of evidence for the exchange of stone adzes between Mainland China and Penghu may be due to sampling error resulting from the limited number of adzes analyzed for this pilot study. We hope to resolve this problem by analyzing a larger number of adzes as part of our collaboration with the Fujian Provincial Museum. The regional geology of Fujian may also be a factor. Unlike the southwest coast of Taiwan, the mainland coast is comparatively rich in formations of fine-grained volcanic rock suitable for making adzes. So despite the high quality of the Penghu basalt and its value in western Taiwan because volcanic rock is scarce there, it is possible that Penghu adzes were not carried in numbers to the mainland simply because Fujian offers other more easily accessible sources of adze rock.

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ABSTRACT

This study uses XRF (X-ray fluorescence) and ICP-MS (inductively coupled plasma mass spectrometry) analyses to determine the chemical composition of raw material used in stone tool production. The goal is to identify where stone adzes, which are common in Neolithic sites on the coast of Mainland China, were produced and if they were transported from the production areas to other places. Our study focuses on adzes from three Neolithic sites located on the Fujian coast of Mainland China, opposite Taiwan. The sites date to between 6500 and 3500 B.P. All of the adzes we sampled are made of volcanic rock. A diverse selection of raw materials, including basalts, andesites, and dacites, was used in manufacturing the adzes, indicating that they are made of rock deriving from many different geological formations. None of the adzes have identical chemical signatures. There is no evidence of specialized centers for adze production. Some of the adzes were probably produced locally, while others were obtained through exchange. This project sets the stage for future research to trace the development and the extent of southeast China Neolithic exchange networks. KEYWORDS: China, Neolithic, stone tools, adzes, production techniques, archaeometry, exchange.

APPENDIX. PROVENANCE AND CONTEXT DATA FOR GEOLOGICAL SAMPLES FROM FUJIAN (CHINA)

SAMPLE NUMBER	REGION	TYPE AND CONTEXT (1)	GPS COORDINATES
HG-1-9	Huangguashan	Cb	(2)
FUJ-2	Longhai and Zhangpu	Cl	24°16′0.8″N,118°6′12.3″E
FUJ-5	Longhai and Zhangpu	Cl	24°14′18.2″N,118°3′13″E
FUJ-6	Longhai and Zhangpu	Cl	24°10′10.8″N,118°2′27.2″E
FUJ-13	Longhai and Zhangpu	Cl	(3)
FUJ-15	Longhai and Zhangpu	Cl	(3)
FUJ-33	Minhou	Bl	26°7′29.5″N,118°56′0.8″E
FUJ-35	Minhou	Cb	26°7′38.4″N,118°56′0.4″E
FUJ-36	Minhou	Cb	26°7′38.4″N,118°56′0.4″E
FUJ-37	Minhou	Cb	26°7′38.4″N,118°56′0.4″E
FUJ-40	Dongzhang	Rb	25°42′.05″N,119°12′1″E
FUJ-42	Dongzhang	Rb	25°42′0.7″N,119°13′0.2″E
FUJ-45	Changle	Lq	25°51′.09″N,119°27′0.5″E
FUJ-46	Changle	Lq	25°51′.09″N,119°27′0.5″E
FUJ-47	Fuan	Lr	27°3′0.9″N,119°25′0.2″E
FUJ-50	Fuan	Lr	27°3′0.9″N,119°25′0.2″E

Notes:

1. Abbreviations: Bl, boulder outcrop; Cb, stream cobble; Cl, columnar formation from outcrop; Lq, lava flow exposed at modern quarry; Lr, lava flow exposed in road cut; Rb, residual boulder in colluvium.
2. All Huangguashan geological samples are from the stream immediately adjacent to the excavation site.
3. Exact provenance unknown. Samples collected from modern stone workshop in Zhangpu.