Tracking Neolithic Interactions in Southeast China: Evidence from Stone Adze Geochemistry

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The authors conducted a sourcing study of stone adzes recently excavated from the Damaoshan site on Dongshan Island, Fujian province, China. They used XRF, ICP-MS, and petrographic thin-section techniques for geochemical and petrographic analysis of six stone adzes from the site and three geological samples from Dongshan Island. The chemical data of these samples compared with other lavas in Fujian, Zhejiang, Penghu, and Taiwan suggest that the Damaoshan people imported stone raw materials either from the Penghu Archipelago in the Taiwan Strait or from the Niutoushan area on the Fujian coast. This indicates that exchange networks along the southeast coast of China, and possibly spanning the Taiwan Strait, had developed as early as 4300–5000 yr B. P. © 2005 Wiley Periodicals, Inc.

INTRODUCTION

Geochemical and petrographic techniques have increasingly become preferred methods for sourcing studies of stone tools in archaeology (Odell, 2004). Techniques such as petrographic thin-section, X-ray fluorescence (XRF), and inductively coupled plasma mass spectrometry (ICP-MS) give a more accurate analysis of the properties of rocks that were fashioned into stone tools, thus offering a comparable database for determining their provenance. As part of a research project to study the development of prehistoric interaction spheres on the southeast coast of mainland China and spanning the Taiwan Strait, we conducted a sourcing analysis on stone adzes recently excavated from the Damaoshan site on Dongshan Island, Fujian province, China (Jiao et al., 2004; Figure 1). The study used XRF, ICP-MS, and petrographic analyses of six stone adzes from the site and three volcanic rock samples

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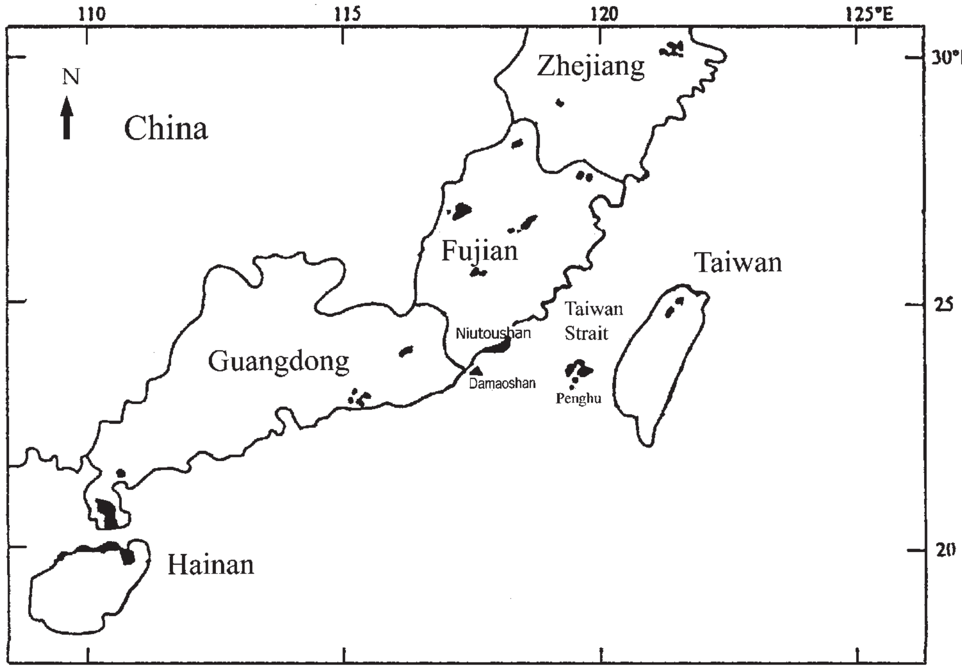


Note. Modified from Chung et al. (1994).

Figure 1. Location of the Damaoshan site and the distribution of basaltic rocks (black polygons) in Southeast China. From Late Cenozoic Basaltic Volcanism Around The Taiwan Strait, SE China: Product of Lithosphere–Asthenosphere Interaction During Continental Extension by Chung, S.-L., Sun, S.-S., Tu, K., Chen, C.-H., & Lee, C.-Y. (1994). Chemical Geology, 112, 1–20.

from Dongshan Island to investigate exchange networks along the mainland Chinese coast and possibly spanning the Taiwan Straight during the period 4300–5000 yr B.P.

THE DAMAOSHAN SITE AND THE GEOLOGICAL SOURCING OF STONE ADZES

The Damaoshan site is located on Dongshan Island in southern Fujian province, China (Figure 1). It is about 150 km west of the Penghu Archipelago and about 200 km west of Taiwan. In 2002, we conducted an archaeological excavation at this site. A significant number of ceramics, stone tools, marine shells, marine fish bones, and terrestrial animal bones were found. The Damaoshan site was dated to ~4300–5000 B.P. based on the calibrated radiocarbon age of marine shells (Jiao et al., 2004).

The excavations also yielded a considerable number of complete adzes, broken adzes, and adze fragments. Based on the plain shape and the shape of cross-section, these adzes were grouped into three types. Type I has a simple rectangular plan shape with quadrangular cross-section, Type II has a rectangular plan shape with

Table I. Adze samples of the Damaoshan site for geochemical analysis.

Sample no.	Context (unit/layer)	Morphology
DMS-2	T4/L2	Broken adze bevel
DMS-4	T3/L2	Adze flake
DMS-5	T2/L2	Broken adze blade and bevel. Plano-convex cross-section. Type III.
DMS-6	T2/L2	Broken adze bevel
DMS-7	T2/L2	Broken adze bevel
DMS-9	T2/L2	Broken adze blade. Triangular cross-section. Type II.

triangular cross-section, and Type III has a rectangular or trapezoidal plan shape with high plano-convex cross-section (close to triangular). The most prominent characteristic of the Damaoshan adze assemblage is the absence of tanged adzes. No grip, tang, or step has been found on any adze from the site.

We selected six adze fragments for our sourcing study. Four of them are pieces of adze bevels or flakes without diagnostic typological features. Of the two samples with typological characteristics, DMS-2 is a Type III adze and DMS-9 is a Type II adze (Table I).

To compare these adzes with the volcanic rocks on Dongshan Island that appear macroscopically similar to the stone tools, we conducted a cursory geological survey near the Damaoshan site and collected geological samples from three locations (Table II, Figure 2).

Altered surfaces on both the adze and geological samples were removed in the laboratory. The fresh parts of each sample were cut into several thin slices using a diamond wheel for petrographic and geochemical analysis. One slice was polished to a petrographic thin-section, and the others were used for geochemical analysis. Samples for geochemical analyses were washed three times with deionized water, then dried, crushed, and powdered with an agate mill for whole-rock major- and trace-element analyses.

Whole-rock major oxide abundances were analyzed by using a Phillips PW1400 sequential X-ray fluorescence spectrometer. Loss on ignition (LOI) was determined

Table II. Geological samples of the Dongshan Island.

Sample no.	Context	Provenance
DRS-1	Basic Dike	Daroushan Hill. Ao'jiao Village, Dongshan County. Dike extends along the southeastern foot of Daroushan Hill, close to sea. About 4 kilometers northeast of the Damaoshan site
DGC-1	Basic Dike	Donggu Village, Dongshan County. Dike extends along the northern foot of Sufengshan Hill, close to sea. It is about 12 kilometers to northwest of the Damaoshan site
DMS-HG	Cobble	A cobble on sand dunes at the northern foot of Damaoshan Hill, about 300 meters north of the current Damaoshan Village.

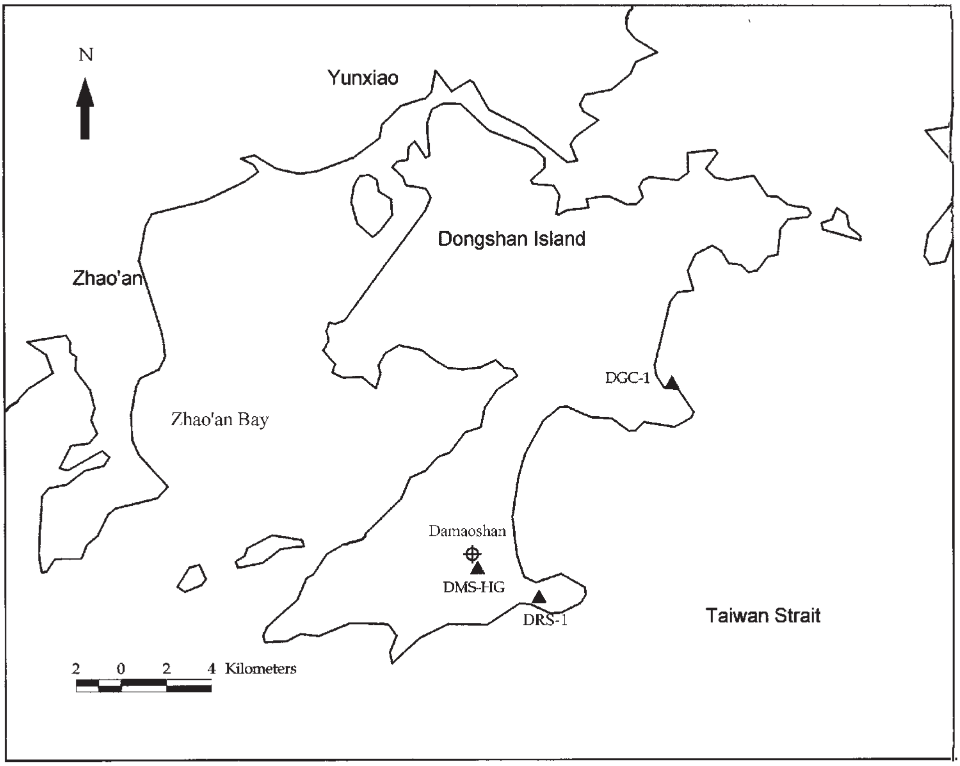


Figure 2. Location of the Damaoshan site and the geological samples from Dongshan Island.

by heating 2 g of samples to 1000°C for 10 hours. Analytical errors for major-element oxides are less than 2% (Table III). Trace elements were analyzed by ICP-MS using the procedures described in Jin and Zhu (2000) and Zhang et al. (2002). The analytical error for most trace elements is $<$4% and about 6% for Ni, Sc, Co, and V (Table IV).

GEOLOGICAL BACKGROUND

Southeast China is an assembly of allochthonous continental terranes (Chung et al., 1994). Cenozoic basaltic rocks, mainly basanite, basalt, trachy-basalt, and basaltic andesite, are sparsely distributed in few areas in the Fujian and Zhejiang provinces along the southeast coast of mainland China and the island of Taiwan. However, the 64 islands of the Penghu Archipelago in the Taiwan Strait are mostly composed of basaltic rocks (Chen, 1990; Flower et al., 1998; Liu, 1999; Zou et al., 2000; Figure 1). These gray and black fine-grained basalts were generated during continental extension (Chung et al., 1994); they are usually underlain by metamorphic rocks, granites, and sedimentary rocks (Liu, 1999).

Table III. Major element oxide contents (wt %) of the adzes from the Damaoshan site and geological samples from Dongshan Island.

Sample no.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	MnO	CaO	Na_2O	K_2O	P_2O_5	LOI
DRS-1	57.86	0.75	16.95	2.50	4.47	5.67	0.12	5.60	3.38	2.54	0.15	1.11
DGC-1	60.86	0.77	17.15	2.91	3.45	3.17	0.11	6.05	3.21	2.05	0.27	0.90
DMS-HG	70.49	0.27	11.91	3.32	5.71	0.83	0.18	7.07	0.00	0.14	0.06	0.97
DMS-2	64.96	0.81	20.47	1.24	4.31	1.68	0.10	0.51	0.65	5.07	0.20	1.23
DMS-5	50.82	1.32	14.57	4.76	6.43	8.77	0.16	11.81	0.99	0.03	0.31	2.30
DMS-6	47.83	1.19	16.14	3.83	7.54	9.35	0.18	12.66	1.05	0.04	0.18	2.23
DMS-7	54.03	1.31	14.99	1.80	9.80	9.07	0.29	5.27	3.32	0.04	0.17	1.41
DMS-9	48.42	1.60	15.93	4.84	6.39	8.22	0.16	13.78	0.34	0.11	0.20	1.93
DMS-4	54.65	1.01	15.04	2.55	6.45	7.86	0.18	9.75	2.31	0.04	0.14	1.21

Note. Data were recalculated to 100% on a LOI-free basis.

Dongshan Island is mainly composed of granite plutons and metamorphic rocks cut by black andesite dikes, but no basaltic rocks are present on the island.

PROVENANCE OF THE STONE ADZES

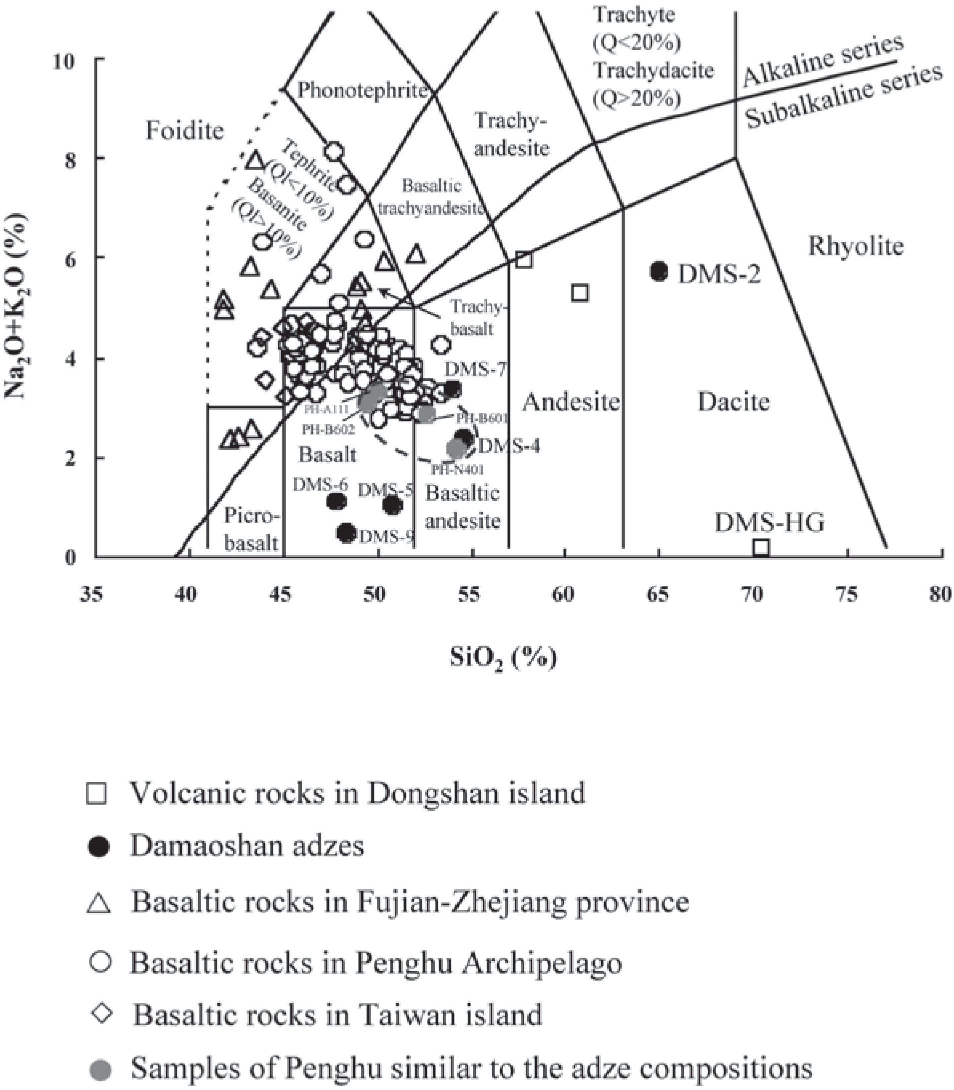
Petrologic observations under microscope show that the geological samples are fresh, but the adzes have slight alteration. All six adzes from the Damaoshan site are made from subalkaline basalts (Figure 4). Three of them (DMS-5, DMS-6, and DMS-9) are made of dark gray and dark green basalts with porphyritic texture and massive structure containing 5–10% phenocrysts of olivine, plagioclase, clinopyroxene, and minor orthopyroxene. The matrix consists of olivine, clinopyroxene, orthopyroxene, plagioclase, and magnetite. The phenocrysts are generally 0.5–1.2 mm (maximum up to 2.5 mm) in size. Two adzes (DMS-4 and DMS-7) are made from basaltic andesites with microporphyritic texture containing 10% pyroxene and plagioclase phenocrysts ranging from 0.2–0.6 mm in size. The groundmass consists of microcrystalline feldspar, pyroxene, and Fe-Ti oxides. One adze (DMS-2) is dacite with microporphyritic texture, and 0.2–0.8 mm phenocrysts (5–10%) characterized by the presence of quartz and sanidine. Of the three geological samples, the two intermediate dike samples (DRS-1 and DGC-1) are andesite-containing phenocrysts of amphibole and plagioclase up to 5 mm in size. The cobble collected at the foot of Damaoshan Hill (DMS-HG) is dacite.

Both the major elements and the petrographic observations indicate that the five basalt and basaltic andesite adzes (DMS-4, DMS-7, DMS-5, DMS-6, and DMS-9) from the Damaoshan site are significantly different from the three geological samples from Dongshan Island (Table III, Figure 3). Although both adze DMS-2 and cobble DMS-HG are dacites, they have significantly different abundances of total alkalis ($Na_2O + K_2O$), indicating they are not from the same source. Therefore, we can conclude that none of the six Damaoshan stone adzes was made of the volcanic raw materials from the immediate vicinity.

Table IV. Trace element concentrations of adzes from the Damaoshan site and geological samples from Dongshan Island.

Element	DRS-1	DGC-1	DMS-HG	DMS-2	DMS-5	DMS-6	DMS-7	DMS-9	DMS-4
Li	17.39	35.63	1.98	38.67	7.70	7.18	15.78	6.99	7.99
Be	1.19	1.49	0.88	3.31	0.72	0.86	1.73	0.69	0.64
Sc	22.56	15.38	3.80	16.76	31.27	28.51	30.35	37.12	25.93
V	179.97	129.03	29.82	107.06	172.77	260.89	223.44	227.37	114.22
Cr	320.35	194.12	324.30	340.20	1095.43	1341.93	1516.30	1031.79	994.01
Co	30.49	20.59	18.79	18.82	58.81	61.63	58.03	58.54	52.69
Ni	143.79	92.89	163.94	182.18	456.94	633.39	677.66	430.06	511.79
Cu	94.63	24.46	59.93	14.11	13.90	23.41	22.58	20.87	28.10
Zn	92.54	94.25	318.03	58.53	107.91	110.06	762.68	141.93	102.65
Ga	17.34	20.13	18.73	26.70	15.88	18.82	15.73	16.88	14.83
Rb	114.57	57.89	1.84	178.69	0.54	1.48	2.00	4.09	1.02
Sr	454.96	789.62	194.28	76.99	369.23	350.00	448.89	373.66	292.42
Y	13.86	19.50	20.79	32.97	22.69	24.76	20.73	24.14	16.09
Zr	108.00	201.57	97.68	222.75	100.37	92.13	136.67	150.62	79.17
Nb	4.58	5.73	5.50	16.54	12.26	9.55	11.81	13.31	7.78
Cs	3.44	2.97	1.81	8.24	0.12	0.34	0.47	0.22	0.20
Ba	455.64	825.02	18.53	824.21	60.02	33.96	48.57	49.26	122.13
La	15.92	33.06	26.49	47.99	11.70	14.18	19.13	12.80	8.93
Ce	33.06	66.10	53.07	95.25	24.88	29.89	39.24	28.89	19.23
Pr	4.15	8.09	6.14	11.24	3.35	4.15	5.04	4.03	2.66
Nd	16.85	31.06	23.28	43.09	14.66	17.17	19.41	17.25	11.36
Sm	3.59	5.92	4.30	8.06	4.23	4.89	4.63	4.85	3.31
Eu	1.01	1.50	1.00	1.41	1.44	1.55	1.32	1.36	1.12
Gd	3.01	4.82	3.94	7.03	4.45	4.93	4.34	4.32	3.29
Tb	0.49	0.72	0.61	1.16	0.75	0.78	0.71	0.75	0.57
Dy	2.70	3.87	3.49	6.55	4.49	4.69	4.15	4.65	3.38
Ho	0.54	0.74	0.72	1.34	0.94	0.96	0.85	0.99	0.66
Er	1.47	2.05	1.95	3.49	2.58	2.48	2.47	2.77	1.89
Tm	0.22	0.29	0.29	0.53	0.39	0.37	0.37	0.40	0.28
Yb	1.35	1.76	1.83	3.27	2.38	2.25	2.21	2.53	1.75
Lu	0.21	0.27	0.28	0.50	0.38	0.35	0.35	0.37	0.27
Hf	2.92	5.11	2.72	6.34	2.77	2.50	3.81	4.08	2.26
Ta	0.51	0.71	0.59	1.31	0.82	0.74	0.88	0.96	0.65
Tl	0.93	0.38	0.10	1.06	0.05	0.07	0.08	0.09	0.06
Pb	12.24	15.95	7.38	5.39	9.55	12.05	390.52	9.62	14.27
Bi	0.55	0.36	2.96	0.61	0.11	0.14	0.79	0.14	0.10
Th	3.75	6.88	6.91	17.42	2.13	2.27	4.92	4.51	1.84
U	0.90	1.67	1.13	3.85	0.62	0.57	1.22	1.14	0.48

Note. Values are reported in ppm.



Note. The data for basaltic rocks from Fujian, Zhejiang, Penghu, and Taiwan are from Chen (1990), Liu (1992), Lee (1994), Chung et al. (1994), and Zou et al. (2000). All sample compositions plotted were recalculated to 100% on an LOI-free basis. The boundary line for alkaline and subalkaline series follows Irvine and Baragar (1971). Dashed lines enclose the four samples of Penghu similar to the adze compositions.

Figure 3. The variation between SiO_2 and $Na_2O + K_2O$ for adzes of Damaoshan and volcanic rocks of whole Dongshan island and in comparison with basaltic rocks from Fujian, Zhejiang Provinces, Penghu Archipelago, and Taiwan island.

To determine the sources of the Damaoshan stone adzes, we compared our samples with the available geochemical data of the Cenozoic basaltic rocks in a broader scope of southeast China, including Fujian, Zhejiang, Penghu, and Taiwan (Chen, 1990; Liu, 1992; Lee, 1994; Chung et al., 1994; Yu, 1989; Zou et al., 2000).

Based on published geological data, the closest subalkalic basalt and basaltic andesites to the Damaoshan site occur in the Penghu Archipelago and the Niutoushan area of southeastern Fujian (Yu, 1989, Figure 1).

A comparison of SiO_2 and total alkali contents demonstrates that the basalt and basaltic andesite Damaoshan adzes are similar to the basalts and basaltic andesites from the Penghu Archipelago in the Taiwan Strait and the Niutoushan area on the Fujian coast, and significantly different from other lavas of Fujian, Zhejiang, and Taiwan (Figure 3). Studies show that the volcanic rocks of Penghu Archipelago (Lee, 1994) and the Niutoushan area (Yu, 1989; Zou et al., 2000) mainly consist of subalkalic basalt and basaltic andesite. This result indicates that the raw materials of the Damaoshan adzes were likely derived from either the Penghu Archipelago or the Niutoushan area.

The trace element comparison further reinforces this observation. Mobilization of K and Na during weathering and alteration can decrease the contents of alkalis and increase the LOI values of volcanic rocks (Wilson, 1989). The lower contents of alkalis in basalts determine that basalts are much more sensitive to these processes than basaltic andesites. The three Damaoshan basaltic adzes (DMS-5, DMS-6, and DMS-9) have lower contents of total alkalis than the published data from Penghu and the Niutoushan lavas (Figure 3 and Table III), suggesting the raw materials were possibly affected by the process of weathering and/or alteration. To avoid any possible variations produced by weathering and alteration, we selected the relatively immobile water-insoluble incompatible trace elements (e.g., Nb, Ta, Hf, Zr, REEs) for provenance analysis (Figure 4).

Four geological samples from three islands of the Penghu Archipelago (PH-N401, Tiezhenyu Island; PH-A111, Penghu Island; PH-B601 and PH-B602, Jilongyu Island) consistently match closely to the Damaoshan adzes in immobile incompatible trace elements (Lee, 1994, pp. 18–19; Figure 4). However, there is no perfect match. For instance, the Yb contents of adzes DMS-5, DMS-6, DMS-7, and DMS-9 are higher than the geological samples from the Jilongyu Island (PH-B601 and PH-B602) and Penghu Island (PH-A111), and adze DMS-4 has a higher Yb concentration than the Tiezhenyu Island sample (PH-N401). These small differences in composition are well within the range that might be generated by magmatic processes (differentiation, magma mixing, assimilation). Alternatively, the small differences might result from differences in the methods by which the data were collected (ICP-MS [this study] and INAA [instrumental neutron activation analysis] and XRF [Lee, 1994]).

Taken together, the data suggest that among the 64 islands of the Penghu Archipelago, Penghu, Tiezhenyu, and Jilongyu islands are likely geological sources for the five basalt and basaltic andesite adzes from the Damaoshan site. However, our data do not exclude the possibility that other islands of the Penghu Archipelago might also be the source, nor do they exclude the Niutoushan area along the coast of Fujian province. Additional trace element data from the Niutoushan lavas are

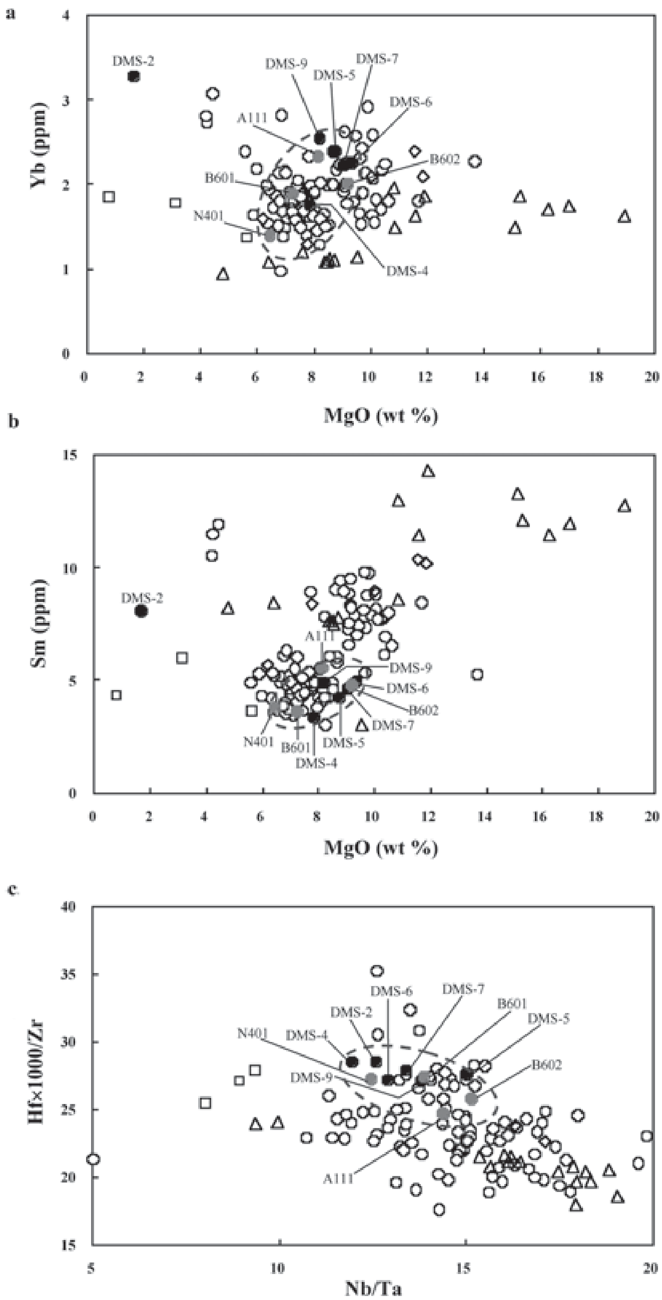


Figure 4. (a) MgO (wt %) versus Yb (ppm) plot. The contents of major element oxides of all samples were recalculated to 100% on a LOI-free basis. (b) MgO (wt %) versus Sm (ppm) plot. The contents of major element oxides of all samples were recalculated to 100% on a loss on ignition (LOI)-free basis. (c) Nb/Ta versus Hf × 1000/Zr plot. The symbols in a–c are the same as in Figure 3.

necessary to determine if that area may also have been a source of raw material for the Damaoshan stone adzes, as suggested by the major element data. The available small amounts of data are collected from a limited number of locations in the Niutoushan area (Yu, 1989; Zou et al., 2000), and they are inadequate for us to further discriminate the source of the Damaoshan basalt and basaltic andesite adzes.

The provenance of DMS-2 is more difficult to determine. This sample has the highest total REE abundances and the lowest compatible element (e.g., MgO, Ni, and Cr) concentrations among the six analyzed adzes despite similarities in most major oxides and some trace element characteristics (Tables III and IV; Figure 4c). The variation between SiO_2 and $Na_2O + K_2O$ in this adze has a positive correlation with the other analyzed adzes (Figure 3), and its Nb/Ta versus Hf $\times$ 1000/Zr plots closely to DMS-4, DMS-6, and DMS-7 (Figure 4c). These characteristics could indicate that the DMS-2 adze raw material was probably the product of fractional crystallization of a parent magma with a composition similar to that of the other adze source rocks. This inference is consistent with the petrologic observation that phenocrysts of adze DMS-2 are composed of quartz and sanidine and those of the remaining five adzes (DMS-4, DMS-5, DMS-6, DMS-7, and DMS-9) consist mainly of olivine, clinopyroxene, and plagioclase. This petrogenic relationship suggests that they all may be derived from sources close to each other. This suggestion is further reinforced by the MgO (wt %) versus Yb (ppm) plot shown in Figure 4a, in which DMS-2 is located around the end of the linearly distributed compositions of Penghu lavas (Figure 4a).

DISCUSSION

Until recently, comparative typological analysis of artifact styles has served as the primary approach in the study of Neolithic period interactions across the Taiwan Strait (cf. Chang, 1995; Chang and Goodenough, 1996). Our sourcing study of the Damaoshan stone adzes, together with other recent similar studies (e.g., Rolett et al., 2000), demonstrates that geochemical and petrographic techniques are effective in addressing this issue. The result of our analysis suggests none of the analyzed stone adzes was made from local raw materials available on Dongshan Island. A comparison of the available geological data suggests that there are two possible sources for these stone adzes: the Penghu Archipelago in the Taiwan Strait or the Niutoushan area of the Fujian coast of the Chinese mainland. Unfortunately, the available chemical data does not allow us to further discriminate these two sources. Nevertheless, the fact that the Damaoshan people imported stone raw materials from outside their island suggests that these oceangoing people were engaged in regional exchange networks through seafaring.

Archaeological investigations indicate that the Penghu Archipelago was populated by people with lifestyles oriented toward the sea during the period of 4300–5100 B.P. (Tsang, 1992, 1995). Artifact typology studies show that these people were engaged in intensive exchanges with their counterparts in southwestern Taiwan (Sung, 1980; Tsang, 1992). Alkaline basaltic stone tools or raw materials, massively produced at the Qimei Island of the Penghu Archipelago, had been exported to southwestern Taiwan on a large scale (Rolett et al., 2000; Tsang and Hung, 2001). Our study indicates that volcanic rocks from the Penghu Archipelago may have been exported to the mainland coast too. Both the major trace element comparisons indicate that the Damaoshan stone adzes have a high degree of similarity with subalkaline basaltic rocks on Penghu, Tiezhenyu, and Jilongyu islands of the Penghu Archipelago. These sources are different from the Qimei island which massively produced stone adzes for southwestern Taiwan.

The Damaoshan site was contemporaneous with many Neolithic sites in the Penghu Archipelago and Taiwan (Jiao et al., 2004; Tsang, 1995). Analysis shows that the Damaoshan artifacts, such as pottery and stone tools, are stylistically similar to those of sites in Penghu and western Taiwan (Jiao et al., 2004). This indirect evidence, together with the result of our sourcing study, suggests that the Damaoshan people were engaged in interaction networks spanning the Taiwan Strait.

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