Ancient genomes document multiple waves of migration in Southeast Asian prehistory

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Southeast Asia is home to rich human genetic and linguistic diversity, but the details of past population movements in the region are not well known. Here, we report genome-wide ancient DNA data from eighteen Southeast Asian individuals spanning from the Neolithic period through the Iron Age (4100–1700 years ago). Early farmers from Man Bac in Vietnam exhibit a mixture of East Asian (southern Chinese agriculturalist) and deeply diverged eastern Eurasian (hunter-gatherer) ancestry characteristic of Austroasiatic speakers, with similar ancestry as far south as Indonesia providing evidence for an expansive initial spread of Austroasiatic languages. By the Bronze Age, in a parallel pattern to Europe, sites in Vietnam and Myanmar show close connections to present-day majority groups, reflecting substantial additional influxes of migrants.

The archaeological record of Southeast Asia documents a complex history of human occupation, with the first archaic hominins arriving at least 1.6 million years ago (yBP) and anatomically modern humans becoming widely established by 50,000 yBP (1–3). Particularly profound changes in human culture were propelled by the spread of agriculture. Rice farming began in the region approximately 4500–4000 yBP and was accompanied by a relatively uniform and widespread suite of tools and pottery styles showing connections to southern China (4–7). It has been hypothesized that this cultural transition was effected by a migration of people who were not closely related to the indigenous hunter-gatherers of Southeast Asia (5, 7–10) and who may have spoken Austroasiatic languages, which today have a wide, but fragmented, distribution in the region (4, 5, 11–14). In this scenario, the languages spoken by the majority of present-day people in Southeast Asia (e.g., Thai, Lao, Myanmar, Malay) reflect later population movements. However, no genetic study has resolved the extent to which the spread of agriculture into the region and subsequent cultural and technological shifts were achieved by movement of people or ideas.
Here we analyze samples from five ancient sites (Table 1; Fig. 1A): Man Bac (Vietnam, Neolithic; 4100–3600 yBP), Nui Nap (Vietnam, Bronze Age; 2100–1900 yBP), Oakaie 1 (Myanmar, Late Neolithic/Bronze Age; 3200–2700 yBP (15)), Ban Chiang (Thailand, Late Neolithic through Iron Age; 3500–2400 yBP (16)), and Vat Komnou (Cambodia, Iron Age; 1900–1700 yBP (17)). We initially screened a total of 350 next-generation sequencing libraries generated from petrous bone samples (specifically the high-yield cochlear region (18)) from 146 distinct individuals. For libraries with evidence of authentic ancient DNA, we generated genome-wide data using in-solution enrichment, yielding sequences from eighteen individuals (Table 1, table S1) (19). Because of poor preservation conditions in tropical environments, we observed both a low rate of conversion of screened samples to working data and also limited depth of coverage per sample, and thus we created multiple libraries per individual (102 in total in our final data set).

We initially analyzed the data by performing principal component analysis (PCA) using two different sets of present-day populations (19). First, compared to a set of diverse non-Africans (East and Southeast Asian, Australasian, Central American, and European), the ancient individuals fall close to present-day Chinese and Vietnamese when projected onto the first two axes, with Man Bac, Ban Chiang, and Vat Komnou shifted slightly in the direction of Onge (Andaman Islanders) and Papuan (fig. S1). To focus on East and Southeast Asian diversity, we then used a panel of 16 present-day populations from the region, with three primary directions in the first two dimensions represented by Han Chinese, Austroasiatic-speaking groups (Mlabri and Htin from Thailand, Nicobarese, and Cambodian, but not Kinh), and aboriginal (Austronesian-speaking) Taiwanese (right, left, and top, respectively; Fig. 1B; compare (20)). Man Bac, Ban Chiang (all periods), and Vat Komnou cluster with Austroasiatic speakers, while Nui Nap projects close to present-day Vietnamese and Dai near the center, and Oakaie projects close to present-day Myanmar and other Sino-Tibetan speakers. Present-day Lao are intermediate between Austroasiatic speakers and Dai, and western Indonesians (Semende from southern Sumatra and Barito from southeastern Borneo) fall intermediate between Austroasiatic speakers and aboriginal Taiwanese.

We measured levels of allele sharing between populations via outgroup $f_3$-statistics and obtained results consistent with those from PCA (table S2). Nominally, the top sharing for each ancient population is provided by another ancient population, but this pattern may be an artifact due to correlated genotype biases between different ancient samples (table S3). Restricting to present-day comparisons, Man Bac, Ban Chiang, and Vat Komnou share the most alleles with Austroasiatic-speaking groups (as Austroasiatic-speaking groups do with each other); Nui Nap with Austronesian speakers, Dai, and Kinh; and Oakaie with Sino-Tibetan-speaking groups. We also computed statistics $f_3(X, Kinh; Australesian, Han)$, where “Australasian” is a union of Papuan and Onge, to search for signals of admixture from outside the East Asian clade in test populations $X$ (increasingly positive values for increasing proportions of deepysplitting ancestry). Present-day Myanmar, Lao, western Indonesians, and Austroasiatic speakers all yield significantly positive values, as do the majority of the ancient samples, with approximately equal results for Mlabri, Nicobarese, and Man Bac (Fig. 2). The Man Bac individuals are additionally mostly similar to each other, except for one, VN29, which is significantly higher than the population mean (Bonferroni-corrected $Z$-test, $p < 0.02$ (19)). Vat Komnou and Ban Chiang also yield high positive values, while Oakaie is modestly positive, and Nui Nap is close to zero ($Z = 1.1$).

Next, we built admixture graph models to test the relationships between the Vietnam Neolithic samples and present-day Southeast Asians in a phylogenetic framework. We began with a scaffold model containing the Upper Paleolithic Siberian Ust’-Ishim individual (21) as an outgroup and present-day Mixe, Onge, and Atayal, to which we added Man Bac, Nicobarese, and Mlabri. The latter three were inferred to have ancestry from a Southeast Asian farmer-related source (∼70%, forming a clade with Atayal) and a deeply diverging eastern Eurasian source (∼30%, sharing a small amount of drift with Onge; $F$-statistics indicate that this source is also not closely related to Papuans, South Asians, or the 40,000 yBP Tianyuan individual (22); table S3). The allele sharing demonstrated by outgroup $f_3$-statistics can be accommodated along the farmer lineage, the deepysplitting lineage, or a combination of the two, but given the closeness of the mixture proportions among the three groups, we found that the most parsimonious model (Fig. 3, fig. S2) involved a shared ancestral admixture event (29% deep ancestry; 28% omitting VN29), followed by divergence of Man Bac from the present-day Austroasiatic speakers, and lastly a second pulse of deep ancestry (5%) into Nicobarese (19).

Finally, to assess the relationships among additional present-day populations, we fit two extended admixture graphs (figs. S3, S4), with the first including Dai, Semende, Barito, Lebbo (from east-central Borneo), and Juang (an Austroasiatic-speaking group from India), and the second including Dai, Semende, Barito, and Lao. The western Indonesians could be fit well with three (but not two) sources of ancestry: Austronesian-related, Austroasiatic-related, and Papuan-related (table S3), in respective proportions of ∼67%, 29%, and 4% (Semende); ∼37%, 60%, and 2% (Barito); and ∼55%, 23%, and 22% (Lebbo) (19). The Austroasiatic-associated component was inferred to be closer to
The symmetric position of aboriginal Taiwanese and the Southeast Asia (in some cases in admixed form) also supports previous genetic results and archaeological hints of an early Austroasiatic-associated Neolithic expansion to western Indonesia (25, 26). Overall, Southeast Asia shares common themes with Europe, Oceania, and sub-Saharan Africa, where ancient DNA studies of farming expansions and language shifts have revealed similar instances of genetic turnover associated with archaeologically attested transitions in culture.

**REFERENCES AND NOTES**


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8. Materials and methods are available as supplemental materials.


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SUPPLEMENTARY MATERIALS
www.sciencemag.org/cgi/content/full/science.aat3188/DC1
Materials and Methods
Figs. S1 to S4
Tables S1 to S3
References (27–70)
Fig. 1. Overview of samples. (A) Locations and dates of ancient individuals. Overlapping positions are shifted slightly for visibility. (B) PCA with East and Southeast Asians. We projected the ancient samples onto axes computed using the present-day populations (with the exception of Mlabri, who were projected instead due to their large population-specific drift). Present-day colors indicate language family affiliation: green, Austroasiatic; blue, Austronesian; orange, Hmong-Mien; black, Sino-Tibetan; magenta, Tai-Kadai. Map data from http://www.freeworldmaps.net/asia/southeastasia/physical.html.
Fig. 2. Relative amounts of deeply diverged ancestry. The Y-axis shows $f_d(X, \text{Kinh; Australasian, Han})$ (multiplied by $10^4$) for populations $X$ listed on the x-axis (present-day as aggregate; ancient samples individually, except for points labeled “all”). Symbols are as in Fig. 1. Bars give two standard errors in each direction; dotted lines indicate the levels in Man Bac (top, blue) and Kinh (zero, black). B. C., Ban Chiang.
Fig. 3. Schematics of admixture graph results. (A) Wider phylogenetic context. (B) Details of the Austroasiatic clade. Branch lengths are not to scale, and the order of the two events on the Nicobarese lineage in (B) is not well determined (19).
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<th>ID</th>
<th>Lib.</th>
<th>Date (yBP)</th>
<th>Site</th>
<th>Country/period</th>
<th>Lat.</th>
<th>Long.</th>
<th>Sex</th>
<th>Mt Hap</th>
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Calibrated radiocarbon dates are shown in bold (95.4% confidence interval, rounded to nearest 5 years); dates in plain text are estimated from archaeological context. Lib., number of sequencing libraries; Cov., average coverage level for 1.2 million genome-wide SNP targets; N, Neolithic; LN, Late Neolithic; BA, Bronze Age; IA, Iron Age.
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