

An Analysis of Prehistoric Canid Remains from Thailand

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The prehistoric settlement site of Ban Chiang has yielded the remains of canid bones covering the period from *c.* 3500 BC to the present. These, and bones from related sites in northeast Thailand, were compared by multivariate means, with modern comparative samples of the wolf, dingo, cuon and jackal. Both in terms of size and shape, the prehistoric dog, though small, has affinities with the wolf. Since wolves are not indigenous to Thailand, the prehistoric dog was an exotic feature of the first agriculturalists there, and raises interesting problems on their origins.

Keywords: BAN CHIANG, THAILAND, DOMESTICATION, DOG, WOLF, JACKAL, DINGO, CHINA, PREHISTORY, MULTIVARIATE ANALYSIS.

Excavations at four prehistoric sites in northeast Thailand have produced a series of canid bones, covering the period between *c.* 3500 BC and the present. Of these sites, the best documented is Ban Chiang, Udon Thani Province (Gorman & Charoenwongsa, 1976). The site levels comprise a series of burial and occupation layers ascribed to six prehistoric phases. There follows evidence for protohistoric occupation, and indeed, the mound is still occupied. In their analysis of the faunal spectrum, Higham & Kijngam (1979) have shown that over 60 species were exploited, ranging from domestic cattle and pigs to a variable assemblage of shellfish, small mammals, amphibians and wild ungulates. They have suggested that the first two millennia of the site's prehistory saw swidden cultivation of rice allied with broad spectrum foraging. By *c.* 1600 BC, economic change saw the introduction of wet rice cultivation, ploughing and the first use of iron. This technique of growing rice remains the basis of the economy to this day.

Like Ban Chiang, the other excavated sites in northeast Thailand reveal settlement near low-lying small stream flood plains, and an economy based on rice and animal husbandry but with widespread foraging during the earlier cultural phases. Each site has yielded canid bones. While faunal assemblages from all sites have now been published (Higham, 1975; Kijngam, 1979), the details of the canid bones have been deferred pending the collection and analysis of the necessary comparative data.

The literature on prehistoric dogs from mainland southeast Asia is almost silent, yet it has been suggested more than once that it is an area of considerable potential importance. Thus Lawrence (1967) and Olsen & Olsen (1977) have both placed the origin of the early domestic dogs of America in east Asia. There is now an extensive literature

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on the early domestic dogs in the Middle East and Europe, indicating an ancestry among the late Pleistocene or early Holocene wolf (Clutton-Brock, 1977) while Gollan's (pers. comm.) recent analysis of the dingo indicates origins in the western Indian subcontinent, probably from *Canis lupus pallipes*.

In turning to the Thai canid material, attention is first directed towards clarifying zoological affinities. The role of the canids within the economy will then be reviewed and the implications assessed. It is possible that the bones could derive from a number of sources. The cuon (*Cuon alpinus*) is indigenous to southeast Asia, as is the golden jackal (*Canis aureus*). If domestic dog is in question, it could be descended from the jackal or wolf. The wolf, however, is not native to Thailand, the nearest indigenous sources being western China (*Canis lupus chanco*) or the Indian subcontinent (*Canis lupus pallipes*), see Ellerman & Morrison-Scott (1966) and Clutton-Brock, Corbet & Hills (1976). In order to illuminate the possible ancestry of the prehistoric specimens, crania and mandibles from *Cuon*, *Canis aureus*, and *Canis lupus chanco* and *pallipes* were studied in the British Museum (Natural History). The same bones from the dingo were also considered, and a collection of sexed crania and mandibles from the modern Ban Chiang village dog was assembled.

Two complementary analyses have been undertaken. Firstly, selected dimensions from all samples were subjected to discriminant function analyses to determine their mutual affinities in terms of size and shape. Secondly, points of consistent but non-parametric differences in shape were sought. The choice of which dimensions to record for the multivariate analysis turned on those parts of the skull and jaw which are expected to diverge from the wild form with domestication (see Table 1). As Lawrence (1967) has shown, these include reduction in mandibular length but not necessarily in the size of the teeth, and a broadening of the rostrum. The size of the auditory bulla was included, since visual inspection showed it to be a prominent feature in the skull of *Canis aureus*.

The computer programme BMDO7M (Dixon, 1973) was used for the discriminant function analyses. In the first analysis, the single complete prehistoric cranium and mandible was compared with all the modern comparative samples (Figures 1 and 2). This specimen was found as a grave offering in Burial 13 (c. 500 BC). All limb bones of this specimen had fully closed epiphyses and the permanent dentition was present. The incisors bore slight wear, but molars and premolars were unworn at death. The cranium comes from a subadult specimen. All 27 variables were analysed using the programme. Figure 1 shows the specimens plotted against their values for the first two discriminant functions, where these between them account for 91% of the total variation in the data. It can be seen from the figure that the analysis shows a clear distinction between the cuon and jackal, and the other species. The greater size of the Chinese relative to the Indian wolves is also evident. The prehistoric specimen is most closely related to the modern village dog of Ban Chiang.

In order to eliminate the effect of size on the apparent differences between the different species, another discriminant function analysis was carried out. This was based upon variables 2 to 27 of Table 1, with each of these variables being divided by variable 1 (the condylobasal length) prior to the analysis. The first two discriminant functions in this case account for 88% of the total variation in the data. As in the first analysis, a plot of the specimens against their values for the first two discriminant functions (Figure 2) shows that the prehistoric skull has close affinities with the modern dog, and is considerably closer to the wolf than the jackal.

The sample of fragmentary prehistoric mandibles comes from four sites, and covers the period between the fourth millennium and the recent past. These were first analysed on the basis of the variable number of dimensions available for each fragmentary

specimen (Table 4). As may be seen, the distribution is discrete given the heterogeneity of the sample. Again the closest affinities are with the modern dog. The missing dimensions for the prehistoric specimens were subsequently estimated using the regression technique that is described in Appendix 1, and two discriminant function analyses were carried out. It is recognised that the basis for the computation of the missing values includes wild canids, and that this should be expected to bias estimated dimensions

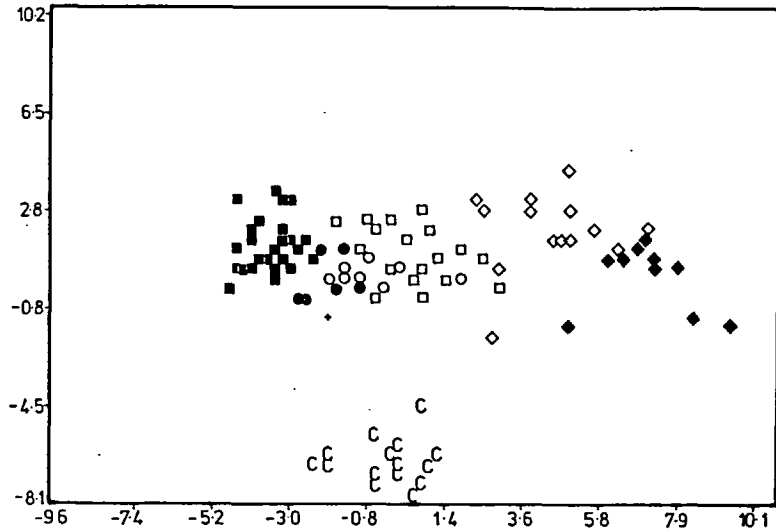


Figure 1. Results of a discriminant function analysis using all of the 27 variables shown in Table 1 (without any transformations). Key: C, *Cuon javanicus*; ●, *Canis familiaris* Ban Chiang ♀; ○, *Canis familiaris* Ban Chiang ♂; ■, *Canis aureus*; ◆, *Canis lupus chanco*; ◇, *Canis lupus pallipes*; □, *Canis familiaris*, dingo; +, prehistoric specimen.

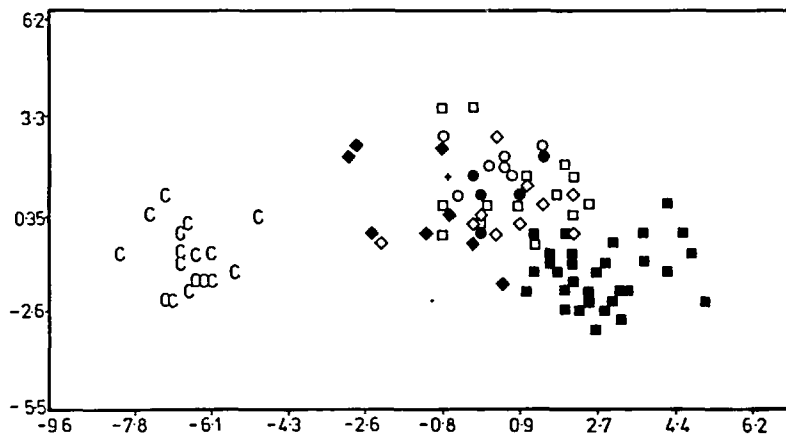


Figure 2. Results of a discriminant function analysis on variables 2 to 27 of Table 1, with the effect of size removed by dividing each of the measurements by the value for variable 1 (condylobasal length). For key see legend to Figure 1.

Table 1. Means and standard deviations for modern and prehistoric cranial and mandibular dimensions

| | <i>C. familiaris</i> ♂ | | <i>C. familiaris</i> ♀ | | <i>C. aureus</i> ♂ | | <i>C. aureus</i> ♀ | | <i>C. l. chanco</i> | |
|------------------------------------|------------------------|-------|------------------------|------|--------------------|------|--------------------|------|---------------------|-------|
| | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. |
| 1. Condylbasal length | 162.10 | 10.38 | 154.95 | 8.02 | 145.41 | 6.16 | 142.50 | 4.47 | 213.41 | 12.01 |
| 2. Mastoid breadth | 61.32 | 2.75 | 58.76 | 2.16 | 50.77 | 2.18 | 49.98 | 1.73 | 74.35 | 2.94 |
| 3. Orbit breadth | 32.33 | 3.06 | 32.38 | 2.71 | 24.58 | 2.23 | 24.85 | 1.43 | 42.00 | 5.24 |
| 4. Palate breadth | 54.95 | 2.32 | 53.46 | 1.57 | 49.15 | 2.14 | 47.66 | 1.39 | 72.42 | 3.18 |
| 5. Prosthion-staphylion | 85.03 | 5.59 | 82.18 | 4.42 | 73.69 | 3.43 | 72.58 | 1.94 | 111.77 | 6.66 |
| 6. Staphylion-basion | 69.01 | 5.63 | 64.82 | 3.78 | 64.47 | 2.79 | 63.05 | 3.07 | 91.38 | 5.42 |
| 7. Length auditory bulla | 21.26 | 1.09 | 19.55 | 0.96 | 23.18 | 1.96 | 22.71 | 1.19 | 28.82 | 1.61 |
| 8. Breadth auditory bulla | 15.91 | 1.52 | 14.78 | 0.74 | 15.81 | 0.93 | 16.16 | 0.64 | 19.95 | 1.03 |
| 9. Br. maxilla at canines | 33.87 | 1.24 | 32.42 | 1.81 | 26.98 | 1.22 | 25.82 | 1.03 | 42.53 | 3.67 |
| 10. Length molar row | 17.70 | 0.73 | 16.85 | 1.44 | 18.41 | 0.85 | 17.92 | 0.85 | 23.82 | 1.55 |
| 11. Length premolar row | 46.78 | 3.22 | 44.32 | 2.05 | 41.57 | 1.69 | 40.50 | 1.48 | 62.45 | 3.48 |
| 12. L. upper canine at base | 9.20 | 0.70 | 8.48 | 0.40 | 7.85 | 0.54 | 7.16 | 0.33 | 12.20 | 1.23 |
| 13. LM ¹ | 11.43 | 0.45 | 11.26 | 0.89 | 11.70 | 0.54 | 11.31 | 0.52 | 15.49 | 0.83 |
| 14. Br. M ¹ | 13.72 | 0.83 | 12.85 | 0.92 | 12.93 | 0.76 | 12.53 | 0.58 | 18.15 | 1.59 |
| 15. L. PM ⁴ | 17.40 | 0.84 | 16.85 | 1.09 | 16.16 | 0.94 | 15.60 | 0.60 | 23.43 | 1.35 |
| 16. Br. PM ⁴ | 8.73 | 0.59 | 8.62 | 0.63 | 8.26 | 0.48 | 7.68 | 0.51 | 12.45 | 0.63 |
| 17. L. pal. fiss.—staphylion | 61.42 | 4.40 | 59.46 | 4.22 | 53.83 | 2.92 | 53.27 | 2.13 | 79.72 | 5.15 |
| 18. L. akromion-basion | 44.53 | 2.55 | 44.07 | 2.72 | 37.95 | 1.84 | 37.26 | 1.28 | 56.94 | 3.67 |
| 19. Length mandible | 128.37 | 8.59 | 122.40 | 6.63 | 112.33 | 4.53 | 109.56 | 3.05 | 168.78 | 10.69 |
| 20. Br. mandible at M ₁ | 10.11 | 0.90 | 9.33 | 0.61 | 8.31 | 0.45 | 7.88 | 0.44 | 13.47 | 1.13 |
| 21. Br. articular condyle | 21.35 | 2.80 | 21.51 | 1.97 | 18.46 | 1.64 | 18.15 | 1.09 | 29.74 | 3.82 |
| 22. Ht. mandible at M ₁ | 21.78 | 1.79 | 20.26 | 1.11 | 16.98 | 0.94 | 16.46 | 0.96 | 27.34 | 1.90 |
| 23. LM ₁ | 19.82 | 0.72 | 18.95 | 0.56 | 18.63 | 0.91 | 17.99 | 0.58 | 26.83 | 1.13 |
| 24. Br. M ₁ | 7.82 | 0.28 | 7.52 | 0.60 | 7.20 | 0.34 | 6.70 | 0.55 | 10.63 | 0.58 |
| 25. L. M ₁₋₃ | 32.92 | 1.11 | 31.07 | 1.13 | 30.67 | 1.30 | 29.85 | 1.01 | 41.94 | 1.76 |
| 26. L. PM ₁₋₄ | 37.33 | 3.04 | 35.70 | 2.21 | 33.10 | 1.48 | 32.71 | 1.20 | 48.08 | 3.49 |
| 27. Br. lower canine | 6.01 | 0.37 | 5.72 | 0.44 | 5.08 | 0.32 | 4.61 | 0.17 | 8.20 | 0.82 |

Table 1—continued

| | Citon δ | | Citon η | | C.l. pallipes δ | | C.l. pallipes η | | C.f. "dingo" | | Ban Chiang Burial 13 |
|------------------------------------|----------------|------|--------------|------|------------------------|-------|----------------------|-------|--------------|------|----------------------|
| | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | |
| 1. Condylobasal length | 173.46 | 6.26 | 168.68 | 9.12 | 205.75 | 12.77 | 191.46 | 14.85 | 180.57 | 8.54 | 141.00 |
| 2. Mastoid breadth | 66.11 | 2.47 | 64.18 | 3.50 | 70.90 | 3.58 | 66.30 | 2.92 | 65.78 | 2.50 | 57.50 |
| 3. Orbit breadth | 36.13 | 2.96 | 34.87 | 2.85 | 39.01 | 4.87 | 34.80 | 5.75 | 34.66 | 2.32 | 29.30 |
| 4. Palate breadth | 61.28 | 2.85 | 60.90 | 2.72 | 68.41 | 4.26 | 64.11 | 2.77 | 58.86 | 2.81 | 54.60 |
| 5. Prosthion-staphylion | 87.47 | 3.24 | 85.63 | 4.71 | 107.78 | 5.31 | 101.33 | 7.33 | 94.89 | 5.23 | 76.50 |
| 6. Staphylion-basion | 76.76 | 3.26 | 74.23 | 4.39 | 86.06 | 6.46 | 79.78 | 7.74 | 75.66 | 3.39 | 62.00 |
| 7. Length auditory bulla | 25.38 | 1.19 | 25.78 | 1.45 | 28.95 | 1.74 | 27.11 | 2.06 | 25.44 | 1.30 | 19.70 |
| 8. Breadth auditory bulla | 16.27 | 0.59 | 15.58 | 0.61 | 21.40 | 1.41 | 20.51 | 2.64 | 18.63 | 0.90 | 14.10 |
| 9. Br. maxilla at canines | 35.41 | 1.76 | 35.00 | 2.46 | 40.57 | 2.20 | 36.70 | 2.94 | 33.52 | 2.06 | 34.00 |
| 10. Length molar row | 17.94 | 0.85 | 18.21 | 1.15 | 22.27 | 1.12 | 22.46 | 1.29 | 19.56 | 0.76 | 16.50 |
| 11. Length premolar row | 49.20 | 1.71 | 47.70 | 3.16 | 58.97 | 3.23 | 56.05 | 4.09 | 52.81 | 2.34 | 43.40 |
| 12. L. upper canine at base | 9.63 | 0.33 | 9.40 | 0.62 | 11.40 | 0.64 | 10.55 | 0.40 | 9.84 | 0.89 | 8.80 |
| 13. LM ¹ | 12.94 | 0.40 | 12.92 | 0.66 | 14.50 | 0.62 | 14.35 | 0.73 | 12.64 | 0.52 | 10.80 |
| 14. Br. M ¹ | 13.61 | 0.51 | 13.60 | 0.50 | 17.08 | 0.69 | 16.88 | 0.60 | 14.87 | 0.96 | 13.50 |
| 15. L. PM ⁴ | 20.27 | 0.79 | 20.00 | 1.22 | 22.30 | 0.71 | 21.15 | 1.32 | 19.42 | 1.07 | 15.50 |
| 16. Br. PM ⁴ | 9.88 | 0.70 | 9.92 | 0.58 | 10.81 | 0.60 | 10.60 | 0.43 | 9.55 | 0.65 | 7.50 |
| 17. L. pal. fss.—staphylion | 61.35 | 3.02 | 59.97 | 3.29 | 79.52 | 4.09 | 74.66 | 7.08 | 68.63 | 4.24 | 53.60 |
| 18. L. akromion-basion | 51.83 | 2.68 | 49.85 | 3.99 | 52.80 | 3.38 | 48.15 | 2.85 | 50.30 | 2.73 | 38.60 |
| 19. Length mandible | 134.63 | 5.17 | 131.58 | 7.74 | 162.17 | 10.01 | 150.81 | 13.14 | 142.43 | 6.87 | 112.00 |
| 20. Br. mandible at M ₁ | 10.82 | 0.61 | 10.61 | 0.61 | 12.13 | 0.69 | 10.83 | 0.49 | 9.64 | 0.68 | 10.10 |
| 21. Br. articular condyle | 24.27 | 1.56 | 23.77 | 1.79 | 28.12 | 3.23 | 23.71 | 3.15 | 24.01 | 1.94 | 17.00 |
| 22. Ht. mandible at M ₁ | 23.53 | 1.56 | 23.55 | 1.52 | 25.51 | 1.53 | 23.18 | 1.33 | 22.61 | 1.80 | 18.20 |
| 23. LM ₁ | 21.57 | 0.81 | 21.25 | 1.00 | 25.25 | 0.92 | 23.78 | 1.03 | 21.08 | 1.11 | 19.00 |
| 24. Br. M ₁ | 8.42 | 0.39 | 8.56 | 0.27 | 9.45 | 0.82 | 9.18 | 0.39 | 8.29 | 0.52 | 7.70 |
| *25. L. M ₁₋₃ | 29.10 | 1.35 | 28.56 | 1.47 | 40.51 | 2.25 | 39.53 | 1.78 | 34.45 | 1.35 | 30.70 |
| 26. L. PM ₁₋₄ | 37.98 | 1.29 | 37.30 | 2.59 | 45.48 | 2.61 | 43.76 | 3.41 | 43.08 | 2.00 | 33.10 |
| 27. Br. lower canine | 6.75 | 0.34 | 6.45 | 0.57 | 7.77 | 0.49 | 6.91 | 0.58 | 6.45 | 0.47 | 5.80 |

* L. M₁₋₂ for Citon.

towards the wild form. Nevertheless, the results of the discriminant analyses still place the prehistoric fragmentary specimens closer to the modern domestic than any wild sample.

The first of these two analyses was based upon the nine jaw measurements shown in Tables 1 and 4 without any transformations. The first two discriminant functions account for 91% of the total variation in the data and a plot of the specimens against the values for the functions. Figure 3 shows that most of the prehistoric specimens are close to or within the distribution for the modern dog.

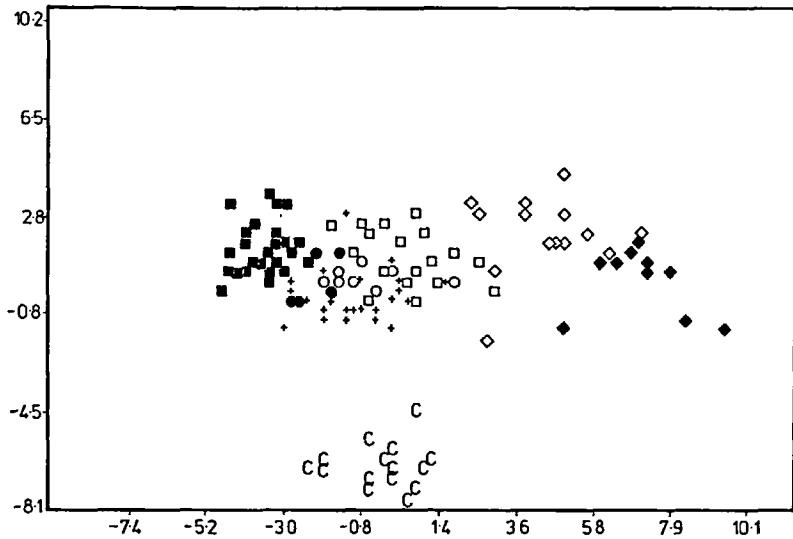


Figure 3. Results of a discriminant function analysis on the 9 jaw measurements shown in Table 1 (variables 19 to 27) without any transformations. Many of the measurements for the prehistoric specimens were estimated from the available measurements using the technique described in the Appendix. For key see legend to Figure 1.

The second analysis on the nine jaw measurements was carried out on these measurements after each one of the measurements was divided by the total for the nine of them. This was done to remove the effect of size. The first two discriminant functions then accounted for 90% of the variation in the data. A plot of the specimens against the first two discriminant functions (Figure 4) confirms the results of the first analysis.

In order to define more closely the areas of difference and similarity between the prehistoric cranium and modern comparative specimens, a series of indices were computed and compared by means of an Analysis of Variance and the Scheffe method for the multiple comparison of means. The indices employed were selected in the light of their high significance for the *F*-test in the Analysis of Variance and to show areas in which domestication affects the skull form (Lawrence, 1967). The similarity in all ratios between canids of the same species but of different sex led to the pooling of the sexed samples in all cases.

Ratios were taken which reflect the shape of the rostrum, crowding of the teeth, development of the auditory bulla and robustness of the jaw (Table 2). It will be seen that in nearly all instances, the prehistoric specimen is extreme when compared with the

comparative samples, and in some cases, exhibits a significant difference. Quite the most discriminatory index is the ratio of breadth of the maxilla at the canines to the condylobasal length of the skull. The maxilla in modern dogs and the prehistoric specimen are equally broad relative to length. It becomes increasingly narrow relative to skull length in the Chinese and Indian wolves, the dingo and the golden jackal. Other indices which reflect broadening of the rostrum include the ratio of the breadth of maxilla at the canines to the length from the prosthion to the staphylion, the length of the prosthion to staphylion as a proportion of palate breadth, and the length from the prosthion to the palatine fissure relative to the breadth at the canines. The prehistoric and modern dogs have significantly broader rostra than the Indian wolf, the jackal and the dingo, but the Chinese wolf occupies an intermediate position, being statistically indistinguishable to both the Indian wolf, jackal and modern dogs.

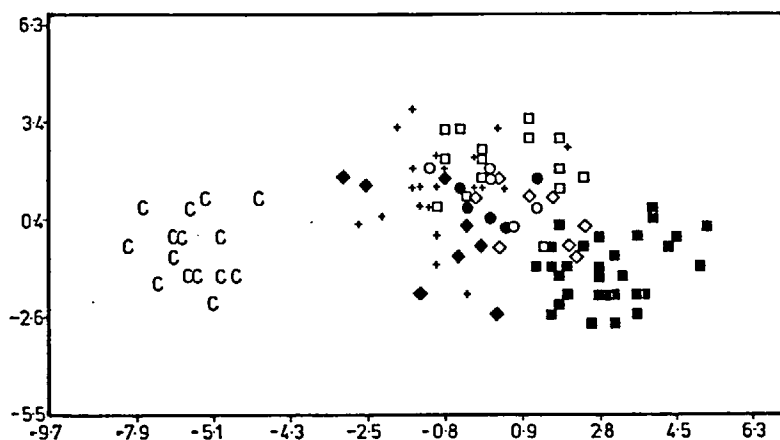


Figure 4. Results of a discriminant function analysis on the nine jaw measurements shown in Table 1 (variables 19 to 27). The effect of size was removed prior to the analysis by dividing each of the measurements by the sum of all nine measurements. Many of the measurements for the prehistoric specimens were estimated from the available measurements using the technique described in the Appendix. For key see legend to Figure 1.

Rather surprisingly, the depth and thickness of the jaw in the modern dog and prehistoric canid seem to be greater relative to jaw length than in the wild comparative samples and the dingo. This difference however, is not significant between samples relative to the prehistoric specimen. Neither visually, nor in terms of the various indices taken is there any evidence for tooth crowding in any of the samples.

The length times breadth dimensions of the bulla were multiplied as an indication of area, and the resultant figure expressed as a ratio of the mastoid width. This latter dimension was selected since it is held to be a conservative area of the cranium and not prone to size change with domestication. The resulting indices show that the modern and prehistoric canids have markedly smaller auditory bullae than the wild wolves and jackals.

The second method for determining the status of the prehistoric bones is by isolating consistent points of morphological difference or similarity with modern specimens. The crania of jackals differs from that of the modern dog in possessing a considerably larger auditory bulla. The processus jugularis in *Canis aureus* is less pronounced and

Table 2. Results of the Scheffe method for the multiple comparison of means

| Variable 1: L. palatine fissure—staphylion/L. prosthion—staphylion | | | |
|--|-----------|----------|---------------------|
| Sample | \bar{X} | <i>s</i> | <i>F</i> = 5.90*** |
| <i>Cuon</i> | 1.427 |] 0.032 | — |
| Ban Chiang B.13 | 1.427 | | |
| <i>C.l.c.</i> | 1.403 |] 0.029 | 0.032 |
| <i>C.f.</i> | 1.388 | | |
| <i>C.f. dingo</i> | 1.383 | | |
| <i>C.a.</i> | 1.367 | | |
| <i>C.l.p.</i> | 1.357 | | |
| Variable 2: L. mandible/Br. mandible | | | |
| Sample | \bar{X} | <i>s</i> | <i>F</i> = 9.43*** |
| <i>C.f. dingo</i> | 14.8 | 0.79 | |
| <i>C.a.</i> | 13.7 |] 0.85 | 1.14 |
| <i>C.l.p.</i> | 13.6 | | |
| <i>C.f.</i> | 12.9 | | |
| <i>C.l.c.</i> | 12.6 | | |
| <i>Cuon</i> | 12.4 | | |
| Ban Chiang B.13 | 11.1 | | |
| Variable 3: Br. maxilla at canines/L. prosthion—staphylion | | | |
| Sample | \bar{X} | <i>s</i> | <i>F</i> = 15.21*** |
| Ban Chiang B.13 | 0.444 |] — | 0.017 |
| <i>Cuon</i> | 0.407 | | |
| <i>C.f.</i> | 0.399 |] 0.023 | 0.025 |
| <i>C.l.c.</i> | 0.381 | | |
| <i>C.l.p.</i> | 0.370 | | |
| <i>C.a.</i> | 0.306 | | |
| <i>C.f. dingo</i> | 0.305 | | |
| Variable 4: Breadth of maxilla at canines/condylobasal length | | | |
| Sample | \bar{X} | <i>s</i> | <i>F</i> = 19.62*** |
| Ban Chiang B.13 | 0.241 |] — | 0.0098 |
| <i>C.f.</i> | 0.210 | | |
| <i>Cuon</i> | 0.206 |] 0.0085 | 0.0117 |
| <i>C.l.c.</i> | 0.199 | | |
| <i>C.l.p.</i> | 0.195 | | |
| <i>C.f. dingo</i> | 0.186 | | |
| <i>C.a.</i> | 0.183 | | |
| Variable 5: Br. maxilla/condylobasal length | | | |
| Sample | \bar{X} | <i>s</i> | <i>F</i> = 6.20*** |
| Ban Chiang B.13 | 0.387 |] — | 0.015 |
| <i>Cuon</i> | 0.359 | | |
| <i>C.f.</i> | 0.343 |] 0.016 | 0.008 |
| <i>C.l.c.</i> | 0.340 | | |
| <i>C.a.</i> | 0.336 | | |
| <i>C.l.p.</i> | 0.334 | | |
| <i>C.f. dingo</i> | 0.326 | | |

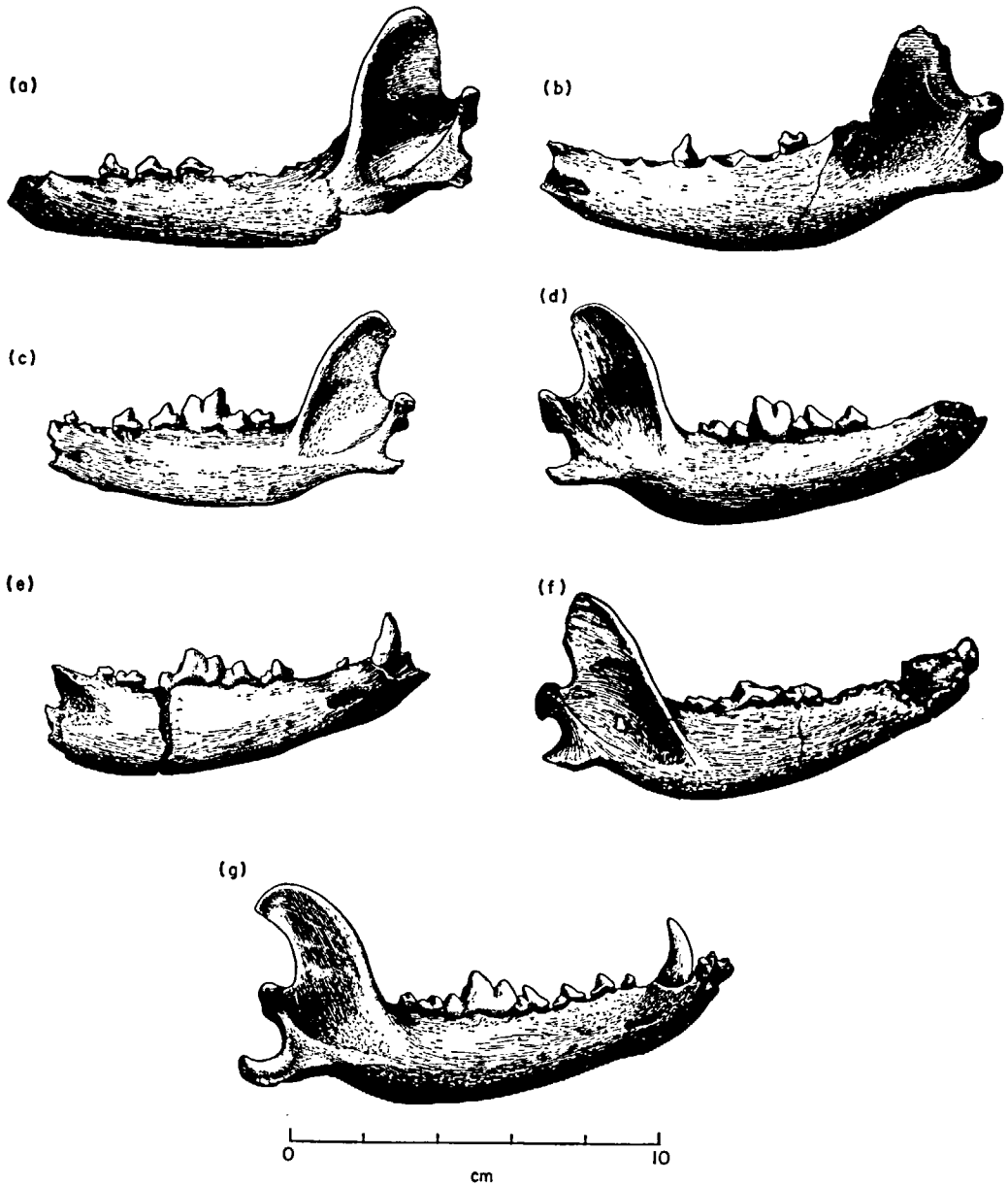


Figure 5. Prehistoric canid mandibles from Thailand: (a) Ban Tong layer 11; (b) Ban Tong Layer 11 (note dental anomaly); (c) Ban Chiang D5 Layer 4; (d) Ban Phak Top Layer 8a; (e) Ban Phak Top Layer 8; (f) Non Nok Tha Burial 8 (early period 1); (g) Ban Chiang: Modern.

On the basis of the multivariate and morphological analyses described above, it is concluded that the overwhelming majority of canid bones from Ban Chiang and related sites come from a domestic dog. The size of the prehistoric and modern breeds is indistinguishable statistically. Bones even from the earliest layers correspond with those from modern animals. The shape of the one complete skull is likewise as in the modern dog. The prehistoric Thai breed is considerably smaller than the dingo, but shares with it close similarities in the shape of the jugular process and the mandible with the wolf. They do, however, differ from the wolf in having a relatively short rostrum, broad palate, and small bullae, all widespread symptoms of domestication in the dog. The degree of shortening, however, did not proceed far enough to induce tooth crowding or displacement.

Table 3. Select limb bone dimensions for modern and prehistoric dogs from Ban Chiang, northeast Thailand

| Provenience | Humerus distal width |
|-------------------------|----------------------|
| D6 L.24 | 28.0 |
| D5/6 L.23 | 29.5 |
| D6 L.22 | 26.6 |
| D6 L.21 | 32.0 |
| D4 L.19 | 27.0 |
| D4 L.19 | 28.2 |
| D4 L.18 | 29.5 |
| D5 L.17 | 27.5 |
| <i>Canis familiaris</i> | 28.4 |
| | Tibia distal width |
| D6 L.26 | 22.3 |
| D4 L.22 | 18.6 |
| D7 L.20 | 19.2 |
| D6 L.18 | 17.1 |
| D5 L.6 | 18.6 |
| Burial 13 | 19.8 |
| <i>Canis familiaris</i> | 20.0 |

The limb bones and jaws of domestic dog from Ban Chiang bear regular traces of cutting, breakage and charring in prehistory. Many mandible fragments have the characteristic that the body is untouched by heat, but the teeth are charred. This taphonomic processing of bone is matched in the other species identified, and suggests that dogs were raised, at least in part, for meat. Indeed to this day, dogs are butchered and consumed in the village of Ban Chiang.

The earliest prehistoric occupants of Ban Chiang and related sites maintained domestic cattle and pigs, were adept at casting bronze implements and probably cultivated rice by means of the wet and/or dry swidden techniques. Over 60 species were identified in the faunal spectrum. All were local, or could have been locally domesticated, with the exception of the dog. As has been mentioned, the nearest indigenous wolves are found in China and in India. Already by c. 5000 BC, the Ch'ing-Lien-Kang culture of the lower Yang-tze had domestic rice and the dog, but no bronze (Pearson, 1979). The Thai upland Hoabinhian sites, which date from the post-Pleistocene period to c. 900 AD, and which provide abundant evidence for a broad spectrum foraging economy, yield

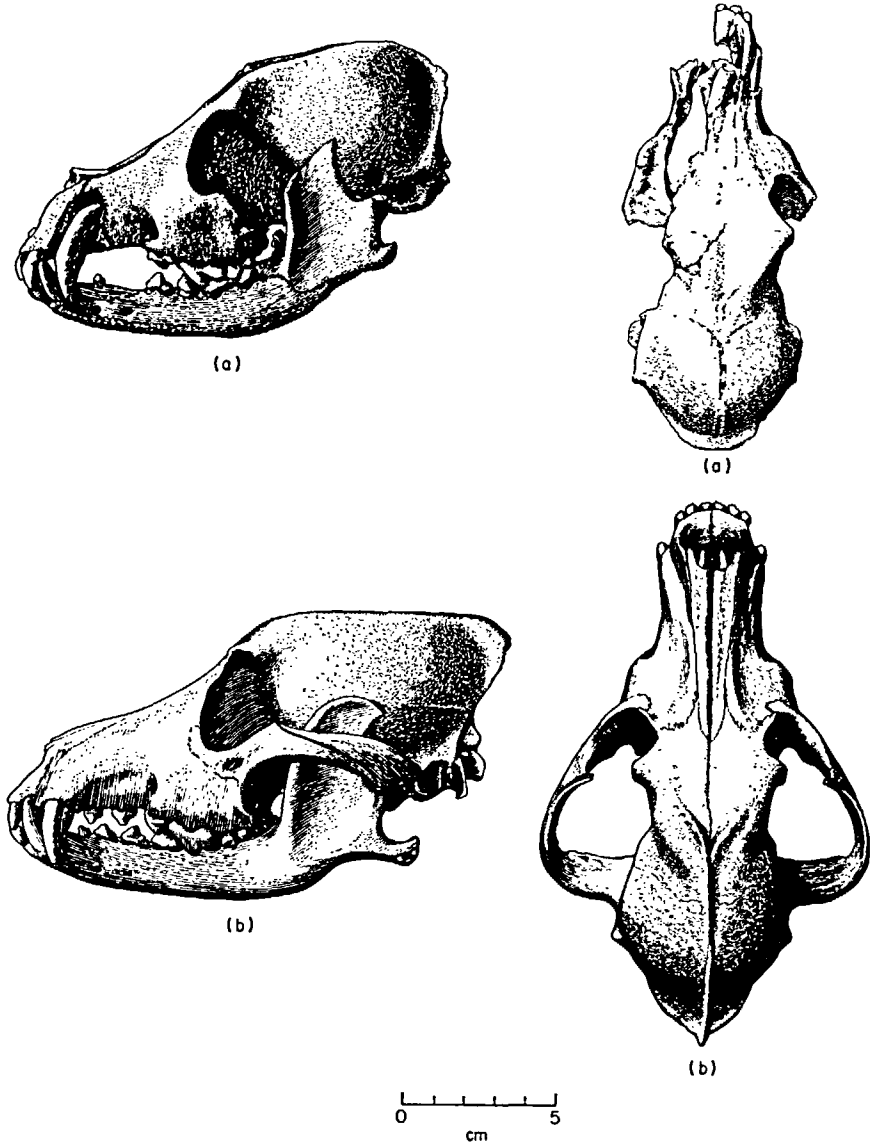


Figure 6. Dorsal and lateral views of the Ban Chiang Burial 13 prehistoric canid cranium (a), and a modern dog from the village of Ban Chiang (b).

no bones from canids. The cultural importance of the dogs from Ban Chiang, then, includes the possibility that they were introduced to the area by the first lowland rice agriculturalists in Thailand or immediately adjacent territory. Already by the earliest occupation layers, dogs were far removed in size from their ancestor, the wolf. The origin of the people and their dogs is currently the most intriguing objective of research in southeast Asia.

Table 4. Dimensions of prehistoric mandibles from Thailand

| Specimen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|--------------|---------|------|--------|--------|--------|-------|--------|--------|-------|
| BC Burial 13 | 112.0 | 10.1 | 17.0 | 18.2 | 19.0 | 7.7 | 30.7 | 33.1 | 5.8 |
| NNT EP | 115.0 | 10.0 | (17.9) | 22.5 | 19.5 | 7.8 | 33.0 | 36.0 | (6.0) |
| NNT 25 | 136.0 | 11.9 | (22.4) | 25.0 | 21.2 | 8.5 | 36.2 | 38.7 | (7.0) |
| BC D6 28 | (117.8) | 10.9 | (18.3) | 18.7 | 21.0 | 8.5 | (34.1) | 34.5 | (6.6) |
| BC D6 24 | (126.1) | 11.1 | (20.6) | 23.0 | 20.5 | 8.3 | 34.5 | (36.4) | (6.6) |
| BC D4 24 | (113.9) | 8.8 | (17.7) | 20.7 | 18.2 | (7.5) | (30.9) | (34.2) | (5.5) |
| BC D6 23 | (131.2) | 10.7 | (20.5) | 23.0 | 20.6 | (8.8) | (33.9) | 39.8 | 6.4 |
| BC D7 21 | (113.5) | 9.5 | (18.1) | 20.6 | 17.9 | (7.5) | (30.7) | (33.6) | (5.6) |
| BC D5 16 | (111.5) | 9.0 | (17.1) | (20.0) | 17.5 | 7.3 | 30.7 | (33.4) | (5.4) |
| BC D6 8 | (104.1) | 8.8 | (18.2) | (19.7) | 17.0 | 6.8 | 26.0 | (31.0) | (4.9) |
| BC D6 6 | (114.8) | 10.6 | (18.8) | 21.0 | 17.5 | (7.6) | 31.0 | (33.5) | (5.7) |
| BC D5 4 | (111.1) | 9.9 | (18.7) | 20.1 | 17.5 | 7.3 | 28.5 | 33.5 | 5.3 |
| BC D6 23 | (110.7) | 10.0 | (17.8) | 19.1 | 18.2 | (7.7) | 30.6 | (32.5) | (5.6) |
| BT 16 | (118.7) | 10.9 | (20.1) | 21.9 | 18.8 | (8.1) | 31.5 | (34.3) | (6.0) |
| BT 14 | (119.3) | 10.5 | (20.1) | (21.7) | 19.9 | (8.4) | 32.5 | 34.0 | (6.1) |
| BT 12 | (119.6) | 10.5 | (19.9) | 22.0 | 20.6 | (8.7) | 33.7 | 33.6 | (6.3) |
| BT 12 | (121.2) | 11.2 | (21.0) | 23.6 | 18.2 | (8.0) | 31.1 | (34.8) | (5.9) |
| BT 12 | (130.4) | 11.2 | (22.5) | 27.4 | 20.0 | 9.1 | 35.2 | 35.3 | (6.6) |
| BT 11 | (124.9) | 10.7 | 19.0 | 26.1 | 19.5 | (8.4) | 33.3 | 37.0 | (6.3) |
| BT 11 | (124.8) | 11.3 | (21.4) | 23.1 | 20.2 | 8.7 | 32.8 | (35.7) | (6.5) |
| BT 11 | 132.5 | 9.6 | 19.2 | 20.2 | 18.7 | 9.7 | 34.8 | 37.9 | (6.6) |
| BT 8 | (121.0) | 10.7 | (20.5) | 23.0 | 19.3 | 7.9 | 32.0 | 34.9 | 6.0 |
| BT 8 | (122.6) | 10.8 | (19.8) | (22.0) | 19.1 | 8.3 | 33.2 | (35.5) | (6.2) |
| BT 4 | (124.6) | 10.8 | (19.5) | 22.1 | 20.0 | (8.7) | 35.0 | (36.2) | (6.5) |
| BPT 8A | 121.5 | 9.8 | 21.8 | 23.0 | 18.5 | 7.9 | 32.2 | 35.2 | 6.1 |
| BPT 8 | (123.5) | 9.5 | (20.1) | 24.3 | 18.7 | 7.6 | (31.5) | 36.5 | 6.0 |
| BPT 9 | (118.6) | 10.8 | (20.0) | 22.5 | 18.8 | 7.5 | (31.7) | 34.2 | (5.9) |
| BPT 8 | (120.9) | 9.4 | (19.4) | 22.9 | (19.0) | (7.9) | (31.8) | (35.8) | (5.9) |

1. L. mandible; 2. Br. mandible; 3. Br. condyle; 4. Ht. mandible at M; 5. LM 1; 6. Br. M 1; 7. LM 1-3; 8. L.PM 1-4; 9. Br. canine; NNT=Non Nok Tha; BC=Ban Chiang; BT=Ban Tong; BPT=Ban Phak Top. Estimated measurements are in brackets (see Appendix 1).

Acknowledgements

The research described in this paper was undertaken with financial assistance from the Ford Foundation and the Evans Fund, Cambridge University. The authors are most grateful for this support. They are also particularly indebted to Dr J. Clutton-Brock, British Museum (N.H.) for her kindness in discussing the canid material and allowing access to the collections. Drawings are by Murray Webb, University of Otago.

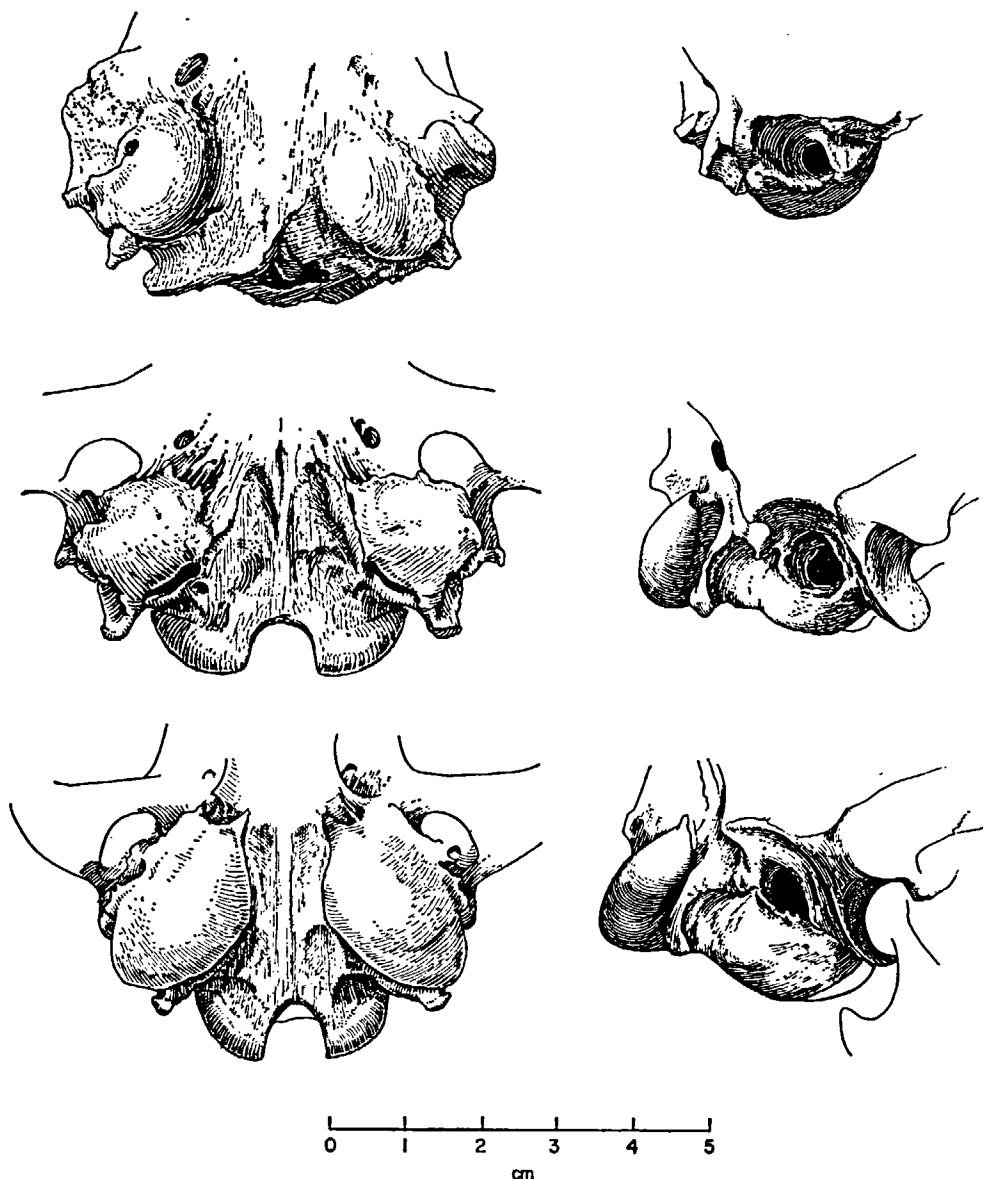


Figure 7. Ventral and lateral aspects of the occipital area in the prehistoric Ban Chiang dog (top), *Canis familiaris* from the modern village of Ban Chiang (middle), and *Canis aureus* (bottom).

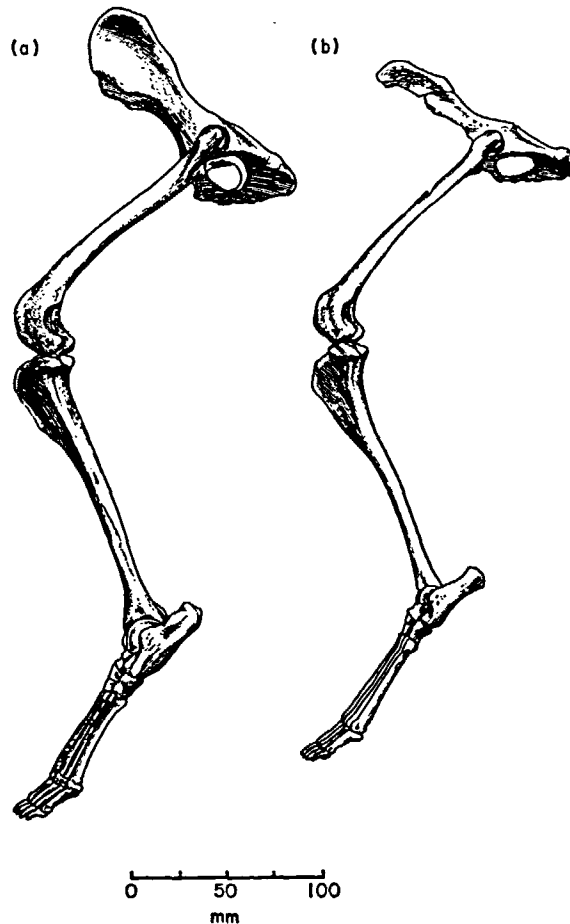


Figure 8. Lateral aspect of rear limb bones from a modern Thai dog (a) and prehistoric dog from Ban Chiang Burial 13 (b).

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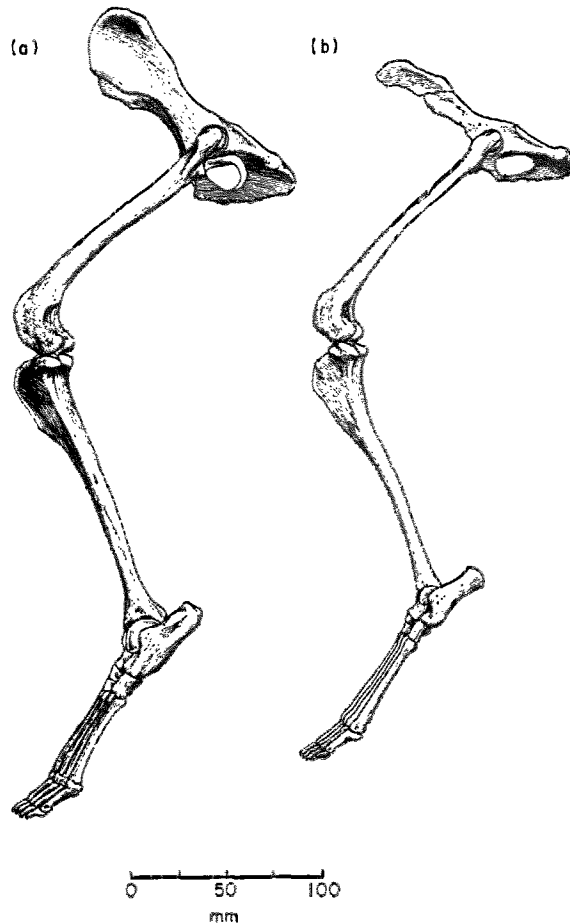


Figure 8. Lateral aspect of rear limb bones from a modern Thai dog (a) and prehistoric dog from Ban Chiang Burial 13 (b).

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Appendix

The Estimation of Missing Measurements for Fragmentary Jaw Specimens

Consider the situation where there are samples of complete individuals for several groups of specimens, and one group containing some fragmentary specimens. This was the situation that was faced in the present study where complete jaws were available for samples of *C. familiaris*, *C. aureus*, *C. l. chanco*, *Cuon alpinus*, *C. l. pallipes* and *C. f.* "dingo", while the prehistoric sample contained only two complete jaws. In order to use standard multivariate techniques to compare the prehistoric group with the other groups it was necessary to estimate the missing measurements in some way. This was done in what appears to be a new way and it therefore seems worth making a note of it.

It was assumed that the measurements on the specimens in the sample from one group follow a multivariate normal distribution, and that the variance-covariance matrix is the same for all groups. These are the usual assumptions made for a discriminant function analysis to compare several groups of individuals.

Consider a particular specimen for which some measurements are missing. Let the missing measurements be x_1, x_2, \dots, x_r and the available measurements be $x_{r+1}, x_{r+2}, \dots, x_n$. The missing and available measurements can then be written in two vectors

$$\underline{x}_1 = \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_r \end{bmatrix} \quad \text{and} \quad \underline{x}_2 = \begin{bmatrix} x_{r+1} \\ x_{r+2} \\ \cdot \\ \cdot \\ x_n \end{bmatrix}$$

and it is a standard result (Anderson, 1958, p. 28) that the expected (mean) value of \underline{x}_1 given the value of \underline{x}_2 is

$$E(\underline{x}_1/\underline{x}_2) = \underline{\mu}_1 + \Sigma_{12} \Sigma_{22}^{-1} (\underline{x}_2 - \underline{\mu}_2) \quad (1)$$

where $\underline{\mu}_1$ and $\underline{\mu}_2$ are the means for the vectors \underline{x}_1 and \underline{x}_2 , and the variance-covariance matrix for the distribution of

$$\underline{x} = \begin{bmatrix} \underline{x}_1 \\ \underline{x}_2 \end{bmatrix}$$

can be partitioned as

$$\Sigma = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix},$$

where Σ_{11} and Σ_{22} are the variance-covariance matrices for \underline{x}_1 and \underline{x}_2 .

Now let

$$\begin{aligned} \hat{\underline{x}} &= \begin{bmatrix} \underline{\mu}_1 + \Sigma_{12} \Sigma_{22}^{-1} (\underline{x}_2 - \underline{\mu}_2) \\ \underline{\mu}_2 + \underline{x}_2 - \underline{\mu}_2 \end{bmatrix} \\ &= \underline{\mu} + \begin{bmatrix} \mathbf{0}_1 & \Sigma_{12} \Sigma_{22}^{-1} \\ \mathbf{0}_2 & \mathbf{I} \end{bmatrix} (\underline{x} - \underline{\mu}) \\ &= \underline{\mu} + \mathcal{A}(\underline{x} - \underline{\mu}), \end{aligned} \quad (2)$$

say, where $\underline{\mu}' = [\underline{\mu}_1', \underline{\mu}_2']$ is the transpose of $\underline{\mu}$, $\mathbf{0}_1$ is an $r \times r$ matrix of zeros, $\mathbf{0}_2$ is an $(n-r) \times r$ matrix of zeros and \mathbf{I} is an $(n-r) \times (n-r)$ unit matrix. Then $\hat{\underline{x}}$ is a vector that contains the actual values for the measurements that are known and estimated values, based upon equation (1), for the measurements that are not known.

Now, if it is assumed that the within-group variance-covariance matrices Σ_{12} and Σ_{22} that are involved in the matrix \mathcal{A} in equation (2) are the same for all groups, then they can be estimated with many degrees of freedom from the samples of complete specimens. Thus the matrix \mathcal{A} can be estimated quite accurately