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Riddle of Cappadocian tablets
Bronze Age Trade - Statistical evidence for sites of ancient towns

A Cappadocian Speculation

In 1925, F. Hrozny discovered the source of the "Cappadocian" tablets near the village of Kűltepe (33° 44' N, 35°, 34'E). These cuneiform tablets provide a foundation for study of the pre-Hittite (*circa* 1940 BC to 1740 BC) network of Assyrian merchant colonies in Bronze Age Anatolia[1]. Bilgic[2] has published the names of 119 towns active in this exchange, as evidenced by their citation on a tablet. The exact location of most of these sites is not known, and historical and archaeological investigations would be greatly facilitated if they could be found. We have used Bilgic's compilation to estimate the geographical position of several of the towns. This is theoretical geography in the sense of Bunge[3], which is conditional on several assumptions. We invoke assumptions to enhance the analysis by applying the leverage obtained from geographical theory. We assume, for example, that mathematical models based on contemporary (largely western) data have a temporally and geographically invariant structure and can be applied to the Cappadocian situation. Our approach differs from several previous attempts[1, 2, 4] to which it should be considered complementary rather than competitive. For example, we do not require the existence of itineraries; the mere mention of two town names on the same tablet is taken to define a relation between these towns. We recognize that one of the simplest geographical relations is distance and attempt to convert the tabular data into geographical distances. If this is possible then it is an almost routine matter to convert these distances into relative positions. Thus it may be possible to specify the actual locations of the towns; that is, to predict their latitude and longitude. The simplest model asserts that places that are mentioned together frequently are probably closer together than are places that are not mentioned together frequently. This spatial decay is similar to the temporal decay of linguistic relations postulated in glottochronology[5], or of isotopic changes used in radiocarbon dating[6]. Our procedure attempts to estimate spatial, rather than temporal, origins and can be considered the geographical equivalent to these methods. It also has comparable limitations. We know of no previous use of the procedure presented here.

On a purely random basis, one would expect the names of large towns to occur more frequently than the names of small towns. The total expectation is thus that the interaction between places depends on the size of the places and the separation between the places. This rather obvious result has been verified in a large number of societies and for many phenomena[7]. Specifically, we expect the interaction to increase as the places get bigger, and to decrease as they are farther apart. Many functions satisfy such a requirement. For social interaction the most common formulation is the so-called gravity model[8]

$$I_{ij} = k\, P_i\, P_j / d^2_{ij}$$

where I_{ij} is the interaction between places i and j; k is a constant depending on the phenomena; P_i, is the population of i; P_j is the population of j; and d_{ij} is the distance between places i and j.

Distance may be in hours, dollars, or kilometres; populations may be in income, numbers of people, numbers of telephones and so on; and the interaction may be in numbers of letters exchanged, number of marriages, similarity of artifacts or cultural traits and so on. The evidence that it "works" has been assembled for more than 20 yr; why such an equation should work is sometimes interpreted as a metaphysical question and continues to be debated[9]. Here, we assume that this model might hold for the number of joint occurrences of place names in merchants' letters. We know of no specific data on this topic, although a modern empirical test seems feasible. The gravity model can of course be inverted to solve for the distance d_{ij}, as can several alternate interaction models[10]. For our purpose this is essential. The step from distances to coordinates can be solved by iterative least squares trilateration techniques[11]. These have recently been generalized in psychology under the heading of multidimensional scaling[12]. For the computation we have used a non-metric computer program made available by Lingoes[13]. This procedure attempts to preserve only the rank order of the distances, not their absolute ratios, and thus partitions spatial interaction models into monotonic equivalence classes. Shepard[14] has emphasized the value of the weaker ordinal assumptions and that the form of the model can be determined after the analysis. This is because the geometric constraints override inconsistencies in the data and minor distinctions between alternate models. The specific equation used for interaction is thus of no great significance.

Bilgic's table gives, for each of 119 towns, the tablets on which the name of that town occurs (a total of 819 tablets is thus referenced). We have taken the number of occurrences of a town name to be proportional to the population of that town. The table can be inverted to list place names by tablet and this is quickly converted to a frequency count. Sixty-five tablets are eliminated from the ensuing analysis since they lead to dead ends, in the sense that they contain the sole reference to a particular town. There remain sixty-two towns occurring on at least two of 754 tablets. These results are most conveniently arrayed in a table of sixty-two rows (one for each town), and sixty-two columns, with the entry at the intersection of any row and column made equal to the number of times that the names of the particular towns occur together on a tablet. This table of joint-mention frequencies is symmetrical so that only the lower half need be completed. The site near Kűltepe has been identified as the Assyrian karum Kanis and most of the tablets can thus be considered to bear the implicit imprimatur "found at Kanis". Thirteen of the tablets (OIP XXVII 1-53) were excavated at Alishar (35° 35' N, 35° 15' E), commonly identified as Akkua[15]; a small number of Cappadocian tablets have also been uncovered at Boğazkőy (40° 02' N, 34° 37' E), now known to have been the Hittite capital Hattus. Out of the possible $n(n-1)/2$ = 1,891 connections, only 187 actually occur if we ignore the implicit imprimatur (which would add forty-four new connections) and the Alishar tablets (adding nine more connections if Akkua is assumed to be implicit on these tablets). This is approximately 10% of all possible connections, and averages three connections per town. The actual numbers of connections ranges from a low of two to a high of twenty-three. The frequency ranges from a 1ow of one joint mention to a high of twelve joint mentions. Some towns are mentioned only once, Purushattum 101 times (seventy-two times in isolation and on twenty-nine tablets with at least one other place name). Our entire analysis is based on Bilgic's work, which is the only currently published complete tabulation. Obvious minor typographical errors have been corrected but Bilgic may have confused regional names with town names, or mistranslated a personal name as a town name, or confused the names of two similar towns, and so on. The most obvious improvement to our analysis would be to use a more extensive collection of data, such as a tabulation prepared from all of the 17,000 Cappadocian tablets excavated so far. Such compilations are in preparation[16] but were not available to us.

Our experiment resulted in the configuration shown in Fig. 1, which is based on all the joint mentions and the estimated populations, without constraints to fix the positions of any locations. The fit of this figure to the available data is high ($r^2 > 80\%$) as is usual for the gravity model, but this is mostly a measure of the internal consistency of the data. The more critical test is to compare our results with known sites. Any solution results in relative coordinates and at least two points must be known in absolute coordinates to determine the scale, and a third point to determine the absolute orientation. For statistical stability many positions should be known in advance. In this case there are sixty-two towns to be located and only Kanis and Hattus (perhaps also Akkua) can be considered known, although reasonable speculations are available concerning the locations of several other sites. In a formal sense our results would allow calculation of a latitude and longitude coordinate for each town, but such precision does not seem warranted until further data become available for analysis.

We can of course compare Our results with other published estimates, most of which are based on a few itineraries. In many cases the interpretations differ and the authors do not agree with each other. Locations are rarely precise, often indicating only the general area. Geographical maps require a more precise specification and we have been able to compare our results with the map given by Orlin[17]. Twenty-nine towns are common to the two studies; the correlation coefficient comparing the twenty-nine locations as given by these two studies is essentially zero. This is disappointing. Both are speculations, of course, one based on a few specific details, the other on 754 tablets indicating general interaction. Our statistical procedure would be more convincing if an extensive network of sites were known exactly and only one or two additional locations were to be found. Orlin's data allow such an estimate to be made, for if it is assumed that his map is correct then this can be incorporated as a weighted constraint in the computer program. On this basis thirty-three locations have been computed from the interaction data and the twenty-nine fixed positions (Fig. 2). We thus obtain coordinates with a precision that is contingent on empirical data, on geographical location theory, and on previous Assyrian scholarship. Five typical results are:

Harana	38°44'N±22'	35°04'E±32'
Huturut	38°46'N±11'	34°03'E±31'
Kussara	38°40'N±2l'	36°49'E±35'
Pahatima	38°33'N±04'	34°31'E±10'
Tilimra	37°49'N±70'	37° 01'E±49'

The probable errors are obtained as an automatic by product of our procedure and can be interpreted in the usual manner. The average of roughly 50 km. may seem too large for the field archaeologist, especially in an area as rich in mounds as central Turkey, but this does not invalidate the technique. As a tool for investigation it has specific data requirements and thus provides a focus for investigation. As in the dating of sites a convergence of evidence is more convincing than a single indicator. Particular sites may deviate from the model but this is then an important method of drawing attention to anomalous situations worthy of more detailed investigation.

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Fig. 1. Predicted location of the more important of the pre-Hittite towns. Based on interaction among sixty-two towns as evidenced by citation on cuneiform tablets. See text for details.

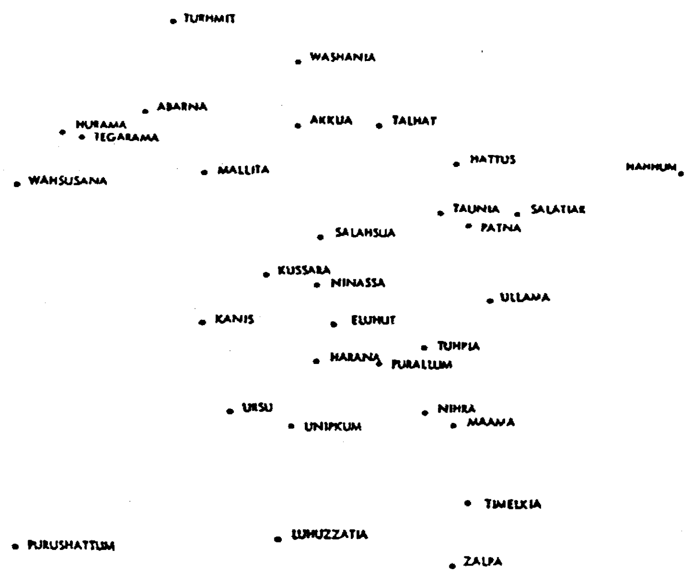

Fig. 2 Predicted location of thirty-three pre-Hittite towns, contingent on the assumption that the towns shown on Orlin's map are correctly located. See text for details.