DAVID W. PACKARD

COMPUTER TECHNIQUES IN THE STUDY OF THE MINOAN LINEAR SCRIPT A[1]

Much recent publication on Linear A has consisted of etymological speculation. The inscriptions have been read as Greek, Luvian, Hittite, North-West Semitic, and Indic, with little attention to non-etymological contextual analysis, and even less to a disinterested appraisal of the phonetic values. Anyone who recognizes the similarity between these methods and those employed in the many fruitless early attempts at deciphering Linear B will have serious doubts about this approach. Almost the only pre-Ventris scholarship confirmed by the decipherment was Bennett's classification of the tablets and Kober's insights into the syllabary. By pursuing limited goals, and without claiming to have deciphered the script, these two scholars made important contributions toward the eventual solution. Others, often assuming identity in phonetic values between Linear B and the Classical Cypriot Syllabary, interpreted the tablets in a wide variety of languages. A like temptation exists now with Linear A where more than half of the phonetic signs resemble Linear B. The obvious and frequently expressed hypothesis that similarity in shape must imply similarity in phonetic value deserves the closest scrutiny. I have tried, with the aid of the computer, to re-examine the problem of the Linear A phonetic values, deliberately avoiding any commitment on the identity of the language.

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[1] The research described here formed a part of my doctoral dissertation, A study of the Minoan Linear A Tablets, Harvard 1967, brief summary in Harvard Stud. Class. Philol. 72, 1968, 397—9. This work would not have been possible without the generous support of Professors George Goold and Susumu Kuno. I intend to publish a full account when the new Zakro tablets become available. In this article I limit myself to a description of the computer techniques which are (and should be) subordinate to the main argument. Since the use of computers is still quite new in Mycenaean studies, some scholars may welcome a description of the kind of help they can give.

Brice's vocabulary of sign-groups formed the basis of my computer analysis[2]. Since my interest was the syllabary, I did not attempt to record the precise disposition of the sign-groups, ideograms and numerals on each tablet. I punched this vocabulary on to IBM cards (one sign-group for each card) with references and an indication of whether the item was complete or whether signs might be missing at the beginning, the end, or both. The signs were represented by L numbers rather than by phonetic equivalents, since the computer can transcribe and print this vocabulary on the basis of any desired phonetic equations.

Brice provides a useful initial and final index of sign-groups but not of signs in medial position. Accordingly I first had the machine construct a complete initial, medial, and final sign index. This index can be printed with L numbers, with any set of phonetic values, or even in the original script (on a CRT plotter).

It is a simple matter to compile statistics on sign frequency from these cards, but we must use caution in interpreting the counts. The sign L 98, for example, occurs in sign-groups about one hundred times. Looking more closely, we discover that thirty-four of these occurrences are in one sign-group, the totalling word (L 98 — L 22). The extremely high frequency of this word biases the statistics in favor of these two signs, and the counts will not represent Linear A as a whole. The program therefore must count signs in each repeated sign-group only once.

In addition to a simple tally, the computer can calculate the percentage of each sign's occurrences in initial, medial and final position. In a syllabary like Linear B, the pure vowel signs tend to have a high ratio of occurrence as word-initials (in Linear B the signs *a* and *e* are 90% initial and 73% initial respectively). The first significant fact which emerges for Linear A is that the two signs which most prefer initial position (L 52: 75% and L 97: 60%) correspond in shape with the Linear B vowel signs *a* and *u*. This helps to confirm these as vowels in Linear A. The sign L 100 is often taken as the vowel *i*; its initial percentage (51%) makes this identification plausible, though not conclusive. Linear B *ku*, *po*, and *pu* are all over 60% initial.

[2] W. C. Brice, Inscriptions in the Minoan Linear Script of Class A, Oxford 1961. Other readings were included, especially those suggested by Raison in Kadmos 1, 1962, 49—58. For convenience in this article I have transliterated Linear A signs according to the normally accepted Linear B parallels (cf. G. Nagy, AJA 69, 1965, 296) without thereby endorsing the validity of the analogies.

Another type of deduction might be attempted on the basis of these frequencies. If signs containing *a* were in general about twice as common as signs containing *e*, one might be surprised to find, for example, that *pa* was ten times more frequent that *pe*. This surprise would be based on the rather doubtful assumption that the frequency of a syllable is predictable from the frequencies of its components. The Linear B sign frequencies happen in fact to show roughly this pattern, except for *jo* and *ja* which are much more frequent than we could possibly predict from other signs with the consonant *j*. Applying this test to the Linear A phonetic values, we find that most fall within the range we might expect, but that several, such as L 24 [*ke*], do not. This certainly does not prove that *ke* is the wrong value, but it suggests that we might look closely at the evidence.

An important step in the analysis of Linear B was Kober's identification of groups of words which seemed to show inflectional or orthographic alternation[3]. She was able to deduce correctly the relationship between several of the phonetic signs without knowing the true values. This kind of evidence should not be ignored for Linear A. Compared with Linear B, the harvest is disappointing. Still, scholars have long pointed to Linear A alternations such as KI.RE.TA_2 / KI.RI.TA_2 as strengthening our confidence in the validity of the phonetic values borrowed from Linear B. Such patterns do give us confidence that these values are not all wrong, but some statistical control is needed. As a preliminary step I had the computer compile several lists: a) pairs of sign-groups which differ only in their final sign, b) pairs which differ in their initial sign, c) pairs which differ by an internal sign. From these lists we can collect pairs of Linear A sign-groups which seem to confirm the transferability of the Linear B phonetic values by the alternations they show (e. g. DA.TA.RO and DA.TA.RE, DI.RA.DI.NA and DI.RE.DI.NA, A.SA.SA.RA and JA.SA.SA.RA). In order to test the significance of these patterns I had the computer construct ten deliberately false decipherments (which I describe below) to help to determine how many such alternations can be collected to support erroneous values.

Evidence from sign alternations and from frequency distribution is internal to Linear A and requires no assumption about the

[3] A. Kober, The Minoan Scripts: Fact and Theory, AJA 52, 1948, 82—103. Furumark made a start with this method in Linear A, in Linear A und die Altkretische Sprache, Berlin 1956 (mimeographed).

identity of the language. It is clearly desirable to maintain a firm distinction between the assessment of phonetic values and the interpretation of lexical items. External evidence does exist, however, which is independent of language and which can perhaps be accepted. Over nine hundred personal names and nearly one hundred place names are attested on the Knossos Linear B tablets. Some of these seem Greek, but many do not. According to Landau's tabulation, about 45% cannot be associated with any known Greek element, and most of his Greek identifications are open to doubt since we have no contextual control over the etymology of a personal name[4]. Given the geographical and chronological proximity of the archives of Hagia Triada and Knossos, we might expect to find some of these Knossos names also in Linear A. Our investigation of Linear A requires us now to make some cautious use of Linear B.

There would be many advantages to having a standard computer text of the entire Linear B corpus. From time to time, the current version could be printed and distributed; in the intervals, any scholar could obtain a personal copy reflecting the latest expert opinion(s) about readings as well as new texts, which will undoubtedly continue to be found at Thebes and elsewhere. But this long-term goal exceeded my immediate problem of finding ways to test the Linear A phonetic values. What I needed was a list of Linear B words, with some indication of which were personal names, place names, general vocabulary words, and so forth. Morpurgo's lexicon provided a convenient source of this information[5]. The sign-groups had been punched previously, I believe, but without indication of possible semantic class. Accordingly, I punched the list again, including an indication of where the word is attested and whether it seems to be a personal name, a place name, or a member of one of about half a dozen other categories.

Once I had prepared the Linear B texts I could ask the computer to transliterate the Linear A sign-groups according to the values inferred from Linear B, and then to search the Linear B vocabulary for matches. There are not many exact matches longer than two signs, but the computer can search for words which are identical except for a final vowel (which might be modified to

[4] O. Landau, Mykenisch-Griechische Personennamen, Uppsala 1958, 237. At an earlier date I punched Landau's complete list on to cards but later abandoned it for Morpurgo's.

[5] A. Morpurgo, Mycenaeae Graecitatis Lexicon, Rome 1963.

follow Linear B inflection), or which match except for at most one internal vowel. If we are prepared to accept only sign-groups from Knossos which Morpurgo lists as personal names or place-names, and if we allow variation only in the final vowel, we find about a dozen Linear B Knossos names in Linear A[6]. It is clear that these have some value as confirmatory evidence for the phonetic values, but, before assuming complete faith in these confirmed values, we must face a difficult statistical problem. How can we be sure that an erroneous assignment of phonetic values in Linear A might not produce parallels with Linear B?

This is the old problem of the monkey at the typewriter composing by chance a Shakespearean sonnet, except that in this case we do not require the Linear A monkey to type an entire sonnet but only a few isolated Linear B words. The monkey would not need to spend much time at the keyboard before chancing on a few words. Are we justified in accepting as evidence single words which our present Linear A phonetic values produce in Linear B?

If the computer has no other use, it can at least imitate a monkey, and that is precisely what it did next by creating ten different sets of deliberately false phonetic values for Linear A in order to test the statistical significance of these matches. We have two independent classes of evidence — internal alternation, and parallels with Linear B — which we can use to try to prove that each of our ten decipherments is correct. The degree to which each kind of evidence appears to validate the deliberately erroneous decipherments will serve as a measure of how little or how much we can rely on it as a guide to the correctness of the values borrowed from Linear B. The Linear B Knossos names which appear in Linear A may serve as an example. The Linear B values produce

[6] In each of the following pairs, the Linear A sign-group is in upper case, and the Linear B word, in lower case italics, is attested at Knossos and classified as a personal name or place-name in Morpurgo's index
SU. KI. RI. TA / *su-ki-ri-ta*, KI. DA. RO / *ki-da-ro*, PA. I. TO / *pa-i-to*, A. RA. NA. RE / *a-ra-na-ro*, KU. RU. KU / *ku-ru-ka*, PA. JA. RE / *pa-ja-ro*, PA. RA. TU / *pa-ra-to*, QA. QA. RU / *qa-qa-ro*, QA. RA_2. WA / *qa-*ra_2*-wo*, TA. NA. TI / *ta-na-to*, DA. MI. NU / *da-mi-ni-jo*, SA. MA. RO / *sa-ma-ri-jo*, possibly A. KA. RU / *a-ka-re-u*, A. TI. KA. A / *a-ti-ka*.

The pair DI. DE. RU / *di-de-ro*[was excluded because of the incomplete state of the Linear B word ("nec amplius"). Other plausible parallels could be cited: DI. KA. TU[/ *di-ka-ta-jo* (ethnic) and the curious double pairs: KU. PA_3. NU / *ka-*pa_3*-no* and KU. PA_3. NA. TU / *ka-*pa_3*-na-to*. This list is more conservative than those sometimes presented because it admits only nearly exact matches with complete Knossos names of at least three signs.

fourteen such names in Linear A (with variation in the final vowel). The average for the other decipherments is 2.5, but the tenth produces six. For pairs of Linear A sign-groups with two identical signs and a third sign showing the same consonant but different vowels (possible inflection), the Linear B values produce eight as against an average of 4.5 for the others. But one gives eleven! The Linear B values are confirmed but not unequivocally. Erroneous values obviously can receive misleading confirmation if the laws of probability are ignored.

We now reach a position where we have confidence that the values borrowed from Linear B are not all wrong, but are not necessarily all right either. The problem becomes one of assessing the signs one by one to determine how much evidence supports each individually. I made a chart summarizing for each Linear A sign the evidence supporting its traditional (Linear B) phonetic value. For signs which were not strongly confirmed, further experiments were indicated.

Next, I instructed the machine to search Linear B again, this time not looking for exact matches with Linear A, but rather looking for matches which would result from various *new* assignments of phonetic values in Linear A. The strategy of the program was to assume that every Linear A sign was correctly transliterated except one, and to allow that one sign to have any value required to find a match with Linear B. After repeating this test for each sign in turn, the program printed a list giving the Linear B yields which would result from each possible phonetic value for each Linear A sign. We learn, for example, that if L 24 (traditionally *ke*) had instead the value *a* we could compare L 24.KI.RU with *a-ki-re-u*; if it had the value *so* we could compare DI.ZA.L 24 with *di-za-so*, or if it had the value *za* we could then read L 24. KI.RU as the place Zakro (cf. Linear B *za-ki-ri-jo*). The list is also printed in the form it assumes when the Linear B values are sought in Linear A. We have, for example, no Linear A sign *si*; this list will suggest many possible candidates. The correct one, I believe, is L 57[7].

Implicit in any direct transference of phonetic values from Linear B to Linear A is the assumption that the two scripts distinguish the same set of vowels and consonants. It is remarkable that this

[7] My reasons for this assignment are set forth in a paper, Contextual and Statistical Analysis of Linear A, in Atti e Memorie del Primo Congresso Internazionale di Micenologia, Rome 1968, I 389—94.

assumption has been made so readily, but once explicit its vulnerability becomes obvious. The Greeks, even if they wanted to copy the Linear A syllabary, may have been prevented from doing so by severe phonological incompatibilities. How might we test the hypothesis that a pre-Greek language of Crete had a different set of vowels or consonants? Goold and Pope pointed to the scarcity of the vowel *o* among the signs which Linear A shares with Linear B[8]. This requires some explanation. Even more surprising is the following observation. We have a list of Linear B sign-groups which seem to be personal names at Knossos and which, according to our phonetic equations, turn up in Linear A. If we disregard the final syllable (which could be influenced by Greek inflection), we find that not one of these words contains the vowel *e* or *o*[9]. This again is a fact which requires explanation. Another obvious place to find evidence for a Cretan substratum would be the non-Greek elements in Linear B at Knossos. This investigation requires statistics on the frequency of each vowel in Knossos place names, personal names and general vocabulary items. If a pre-Greek language did in fact lack one or more vowels represented in Linear B, we might expect this deficiency to be reflected in the statistics for vowel frequency at Knossos. With Morpurgo's index in computer form I could test this by creating graphs for each sign in Linear B showing its relative frequency in each of seven classes of words: Pylos place names, Pylos personal names, Pylos total, Linear B total, Knossos total, Knossos personal names, Knossos place names. We might expect that the most typically Cretan elements would cluster to the right of the graphs, with the Pylian elements to the left, and the average in the center. These graphs can also be compiled for all signs which contain a given consonant or vowel. Examining the graph for all non-final signs containing each vowel, we discover that the vowels *e* and *o* are relatively less frequent on the Knossian side. This could, but need not, be explained on the hypothesis of a lack of these vowels in a Cretan substratum. Many hints about the phonology of the Minoan language(s) must lie hidden in the Linear B tablets from Knossos. With more refined techniques we may be able to draw further conclusions.

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[8] G. P. Goold and M. Pope, Preliminary Investigations into the Cretan Linear A Script, Cape Town 1955, x.

[9] A possible exception would be KU. DO. NI / *ku-do-ni-ja* if the value DO rather than ZU is accepted for L 101.

Contextual analysis and classification, the other foundation for the scientific study of the Linear A texts, does not lend itself to computerization as readily as does the study of the syllabary, though I found it useful to construct for each tablet a list showing: a) other occurrences of the same sign-groups, b) sign-groups which differ from these by only one sign, c) Linear B parallels (to be used with great reserve).

My programs were written in Fortran II and in Assembly Language for an IBM 7094 computer. When the tablets from Kato Zakro are published I intend to rewrite these programs for the IBM 360 (or whatever the current computer may be), and to include the new tablets with the old in the various indices and statistics.