crossarm, is counterweighted, and has proved sturdy and stable in field studies of corn (*6*).

We field-tested three prototype instruments during the 1979 growing season with satisfactory results. The tests were conducted on rangelands in west Texas and on alfalfa, corn, soybeans, and winter wheat at the Beltsville Agricultural Research Center, Maryland. Thirty instruments were tested during the 1980 growing season at locations throughout North America. Some of the collected data appear in Fig. 3.

In addition to the demonstrated uses with vegetation, hand-held radiometers have potential application in any field where radiometric measurements in the 0.3- to 2.5-μm region are of value. The spectral range of the device described in this report may be reset by changing interference filters or detectors.

COMPTON J. TUCKER
WILLIAM H. JONES, WILLIAM A. KLEY
GUNNAR J. SUNDSTROM
NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771

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Decipherment of the Earliest Tablets

Abstract. *The first signs of writing were crudely impressed on clay tablets. These signs are found to represent and stand for clay tokens used for recording prior to writing. The recent decoding of a series of tokens makes it possible to identify the signs as units of grain metrology, land measure, animal numeration, and other economic units.*

The recent identification of a system of clay tokens used for recording/counting as a progenitor of writing invites the reevaluation of the earliest written documents, known as tablets (*1, 2*). This report deals with the first series of tablets which are characterized by crudely impressed signs (Fig. 1). These tablets are usually referred to as "numerical tablets," suggesting that they yield only numerical notations. They will be called here "impressed tablets," and, in light of new evidence drawn from the token system, I will propose a new decipherment of the earliest stages of writing.

The tablets and the signs. About 200 impressed tablets are reported in the literature, coming from excavations in Iran (Susa, Chogha Mish, Godin Tepe, Tepe Sialk, and Tall-i Ghazir), in Iraq (Uruk and Khafaje), and in Syria (Habuba Kabira and Jebel Aruda). They date from about 3150 to 2900 B.C.

Eighteen different signs can be identified on the impressed tablets which, as illustrated in Fig. 2, I interpret as representations of tokens. I view, in particular, the deep circular markings (Fig. 2, columns 1 and 2) as standing for spheres and the shallow circular markings (Fig. 2, column 8) as standing for disks. I equate the short wedges (Fig. 2, columns 9 and 10) with cones and the long wedges (Fig. 2, column 16) with cylinders.

The recent decoding of the meaning of these tokens (*2*) allows me to propose the following decipherment for the tablet in Fig. 1: two "large" measures and three "small" measures of grain (equivalent to about 90 liters of grain). An explanation follows.

The meaning of the wedges, deep circles, and triangles. Jöran Friberg recently documented the fact that the Sumerians and the Elamites used the same system to record grain metrology (*3*, pp. 10 and 20): (i) the most basic unit (about 6 liters of grain), called the *ban* in Sumer, was represented by a wedge; (ii) a unit six times larger, the *bariga*, was represented by a circle; (iii) a fraction of the *ban* was shown as a triangle. I postulate that the shapes of the signs used for grain metrology derive from the tokens in the shape of cones, spheres, and triangles. As a consequence, I consider the small cone to represent the most basic unit of grain. Its shape may be viewed as deriving from the representation of a deep bowl. The sphere will stand, accordingly, for the second most basic unit of grain, of larger size. Its shape may be suggestive of a bag of grain. Large cones and spheres represent still larger units of grain metrology, whereas the plain triangle stands for a fraction of the basic unit.

Fig. 1. Impressed tablet (Gd 73.292) from Godin Tepe, Iran. [Courtesy T. Cuyler Young, Jr., Royal Ontario Museum, Toronto, Canada]

The impression of these tokens on the tablets had the same meaning as the tokens themselves, and, as a consequence, the two small circular impressions and the three wedges on the tablet in Fig. 1 may be read "two 'large' and three 'small' measures of grain." Land measures in Sumer were calculated in terms of the seed ratio necessary for sowing (*4*). It is, therefore, not surprising to find in Friberg that the cones and spheres were also used as units for land measurements (*3*, p. 46). In this case the multiples of the standard Sumerian units, the *iku* (3258 m2) and the *bur* (63504 m2), were expressed by punched cones (Fig. 2, column 11) and spheres (Fig. 2, column 4) and a fraction by an incised sphere (Fig. 2, column 3).

When, how, and why certain signs specifically used for grain and field measurements came to be used for abstract numbers are questions of fundamental importance for the development of mathematics, but they are beyond the scope of this report. In the texts of the Uruk IVa period of 3100 B.C., pictographs in the form of an ear of barley and of a schematized field are added next to the impressed signs in accounts dealing with barley and land to specify that the quantities referred to these commodities, thus suggesting that the process of acquisition

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of abstract numbers was then already under way.

The meaning of the long wedges, shallow circles, and double wedges. In the token system, a series of disks bearing distinctive patterns can be matched with pictographs translated as sheep, ewe, lamb, wool, cloth, and garment. This demonstrates that concepts of related meaning were represented by variations of markings placed on a type of token. One may, therefore, expect that the plain disk was a common unit in the series, which acted as a root. Falkenstein's translation of "slab, block, total circle" (*5*) (Fig. 2, column 8) becomes suspect, and the correct meaning of the plain disk may be provided by Friberg's study. According to his results, a special numeration system was used in Elam to keep track of animals. The signs used were alternatively a wedge standing for one animal (Fig. 2, column 16), a circular shape for ten (Fig. 2, column 8), and a double wedge, apex to apex, for 100 (Fig. 2, column 13) (*3*, p. 21). I interpret the wedge used in the animal numeration system as being the long wedge, which represented the cylinder of the token system. I also postulate that the circular marking used to represent ten animals is the shallow circular marking which stood for a disk (Fig. 2, column 8). It is important to note here that the double cones placed apex to apex which appear on one tablet from Godin Tepe (*6*) and stand for 100 animals, represent an important departure for writing. The sign is not the straightforward representation of a token. The symbol is doubled and exploits for morphology the new possibility provided by two-dimensional design.

The remaining signs. The deep circular markings standing for the spheres and the short wedges standing for cones are by far the most frequently used signs (Fig. 1). They occur, respectively, on 88 and 69 tablets. The reading of these two signs alone provided, therefore, a translation for 85 percent of the tablets. The long wedges standing for cylinders and the shallow circles standing for disks are next in frequency and appear on 30 and 15 tablets, respectively. The remaining signs are rare. An attempt has been made in Fig. 2 to correlate them to known Sumerian pictographs suggesting such translations as "oil," "sweet," and "fat tail sheep."

The decipherment of the impressed tablets has three major consequences. First, it makes available a body of previously enigmatic data and reveals that the impressed tablets bear accounts of foodstuffs consisting mainly of grain and small stock. Second, it provides an insight into the first use of writing. The small amounts of food dealt with suggest that the impressed tablets, like the later pictographic tablets, were receipts of taxes paid by individuals. Third, they illustrate the last stage of quality counting which mathematicians have conjectured preceded the acquisition of abstract numbers.

DENISE SCHMANDT-BESSERAT
Center for Middle Eastern Studies, University of Texas, Austin 78712

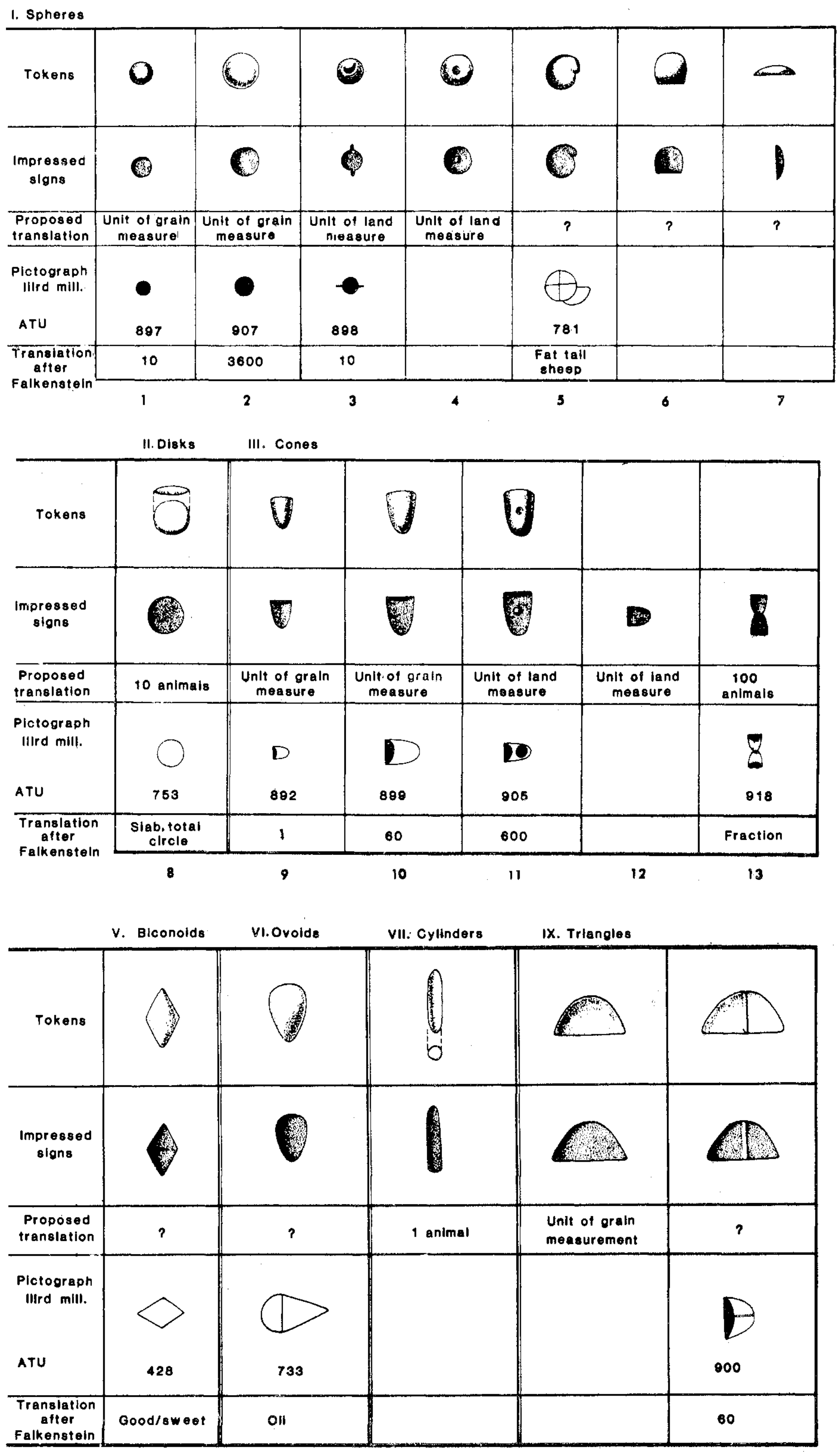

Fig. 2. Chart showing the relationship between tokens, impressed signs, and pictographic signs [see (*5*) for an explanation of ATU numbers].

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Atmospheric Trace Gases in Antarctica

Abstract. *Trace gases have been measured, by electron-capture gas chromatography and gas chromatography–mass spectrometry techniques, at the South Pole (SP) in Antarctica and in the U.S. Pacific Northwest (PNW) (~ 45°N) during January of each year from 1975 to 1980. These measurements show that the concentrations of* CCl_3F, CCl_2F_2, *and* CH_3CCl_3 *have increased exponentially at substantial rates. The concentration of* CCl_3F *increased at 12 percent per year at the SP and at 8 percent per year in the PNW;* CCl_2F_2 *increased at about 9 percent per year at both locations, and* CH_3CCl_3 *increased at 17 percent per year at the SP and 11.6 percent per year at the PNW site. There is some evidence that* CCl_4 *(~ 3 percent per year) and* N_2O *(0.1 to 0.5 percent per year) may also have increased. Concentrations of nine other trace gases of importance in atmospheric chemistry are also being measured at these two locations. Results of the measurements of* $CHClF_2$ *(F-22),* $C_2Cl_3F_3$ *(F-113),* SF_6*,* C_2*-hydrocarbons, and* CH_3Cl *are reported here.*

January 1980 marked the sixth year of our trace gas measurements program at the South Pole (SP). We report here the data obtained over these 5 years, estimate the average annual increases in the concentrations of CCl_3F (F-11), CCl_2F_2 (F-12), CCl_4, CH_3CCl_3, and N_2O, and report the consistency of our measurements of CCl_3F, CCl_2F_2, and CH_3CCl_3 with the emissions estimates. In January 1980 we also measured $CHClF_2$ (F-22), $C_2Cl_3F_3$ (F-113), CH_3Cl, SF_6, CH_4, CO, C_2H_2 (acetylene), C_2H_4 (ethylene), and C_2H_6 (ethane). These data are also included.

We have maintained the objective of quantifying the global trend toward increasing atmospheric concentrations of long-lived gases such as CCl_3F, CCl_2F_2, and CH_3CCl_3, which are released as a result of human activities, primarily at latitudes above 30°N, and which may adversely affect the future global environment (*1*). In order that the picture be more complete, the trends observed in the antarctic atmosphere are contrasted to those observed at (remote) Pacific Northwest (PNW) (~ 45°N) sites during the same period.

The measurements of N_2O, CCl_3F, CCl_2F_2, CCl_4, and CH_3CCl_3 made every January from 1975 to 1980 are reported in Table 1 (*2*). Concentrations for a variety of trace gases, not previously measured in Antarctica, are also shown in Table 1, including $CHClF_2$ (F-22), which is likely to gain environmental importance in the years to come (*1*). We measured these halocarbons and other trace gases, using established electron-capture gas-chromatography techniques (*3*).

The internal consistency in the absolute concentrations reported for each season has been maintained since 1976 by calibration standards. The values in Table 1 are averages over many measurements and represent our best estimates of concentrations in the antarctic troposphere during January of each year. Whenever possible, the concentrations observed in Antarctica were compared with measurements made by P. Fraser, Commonwealth Scientific and Industrial Research Organization, Cape Grim, Tasmania (~ 43°S), and measurements made elsewhere in the Southern Hemisphere. The antarctic measurements have always been consistent with these additional measurements (*2*).

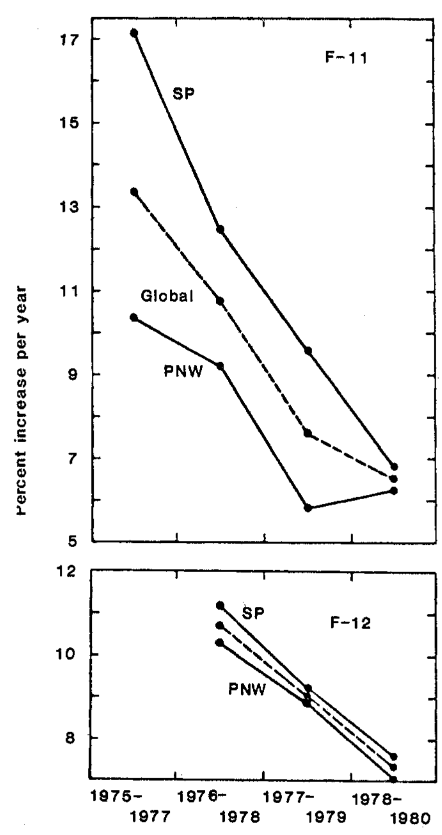

Fig. 1. Rates of growth of CCl_3F (*F-11*) and CCl_2F_2 (*F-12*) during overlapping 3-year periods from 1975 to 1980.

On the basis of the data given in Table 1, we have estimated the increases in the concentrations of CCl_3F, CCl_2F_2, CCl_4, CH_3CCl_3, and N_2O and considered the changes in the north/south (N/S) ratio. The results of these calculations are summarized in Table 2. We found that the time series data are appropriately represented by the (exponential growth) expression

$$\frac{1}{c}\frac{dc}{dt} = \beta$$

where c is the concentration and β is regarded as a constant, thus reflecting the average rates of atmospheric increase during the years when observations were made. In Table 2, we estimated β by using nonparametric statistical methods based on the Theil statistic (*4*); the estimate of the (average) value of β is denoted $\hat{\beta}$. The $\hat{\beta}$ obtained by this method is less sensitive to gross errors than the usual classical least-squares estimates. The numbers we obtained for $\hat{\beta}$ were multiplied by 100 percent to convert them to percentage increases per year. Similarly, we estimated a distribution-free approximate 90 percent confidence interval for β, using the Theil test (*4*). The results are reported in Table 2 as β_L (lower limit) and β_U (upper limit). The concentrations of CCl_3F, CCl_2F_2, and CH_3CCl_3 increased at about 10, 9, and 13 percent per year, respectively, on the average.

The data in Table 1, for 6 years, also indicate that the rate of atmospheric accumulation of CCl_3F and CCl_2F_2 (denoted β) may be slowing down. Such an observation would be consistent with, indeed required by, the leveling off in the global emissions since about 1975 (*5*). A leveling off in the emissions of these

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