two artifacts identical with the Altun Ha specimen in the collection from Coclé in central Panama (*4*). Unfortunately, the two Coclé objects were purchased, and hence they cannot be directly related to the archeological sequence for the area. The Coclé occupation was once thought to fall entirely in the Post-Classic period, but ^{14}C dates from Panama now indicate a span from A.D. 500 or earlier to about A.D. 1300, with the initial date open to considerable question (*5*). The data from Coclé provide a fairly solid basis for assuming that metalworking had progressed sufficiently in the area by or before A.D. 500 to have begun to play a role in trade relationships that extended beyond the borders of central Panama. This assumption is supported by the Altun Ha indication that metallurgy in the Coclé region was coeval with the middle portion of the Maya Early Classic, if not earlier. Hence the Altun Ha discovery provides apparent confirmation of the radiocarbon-dated Panama sequence, as well as evidence of trade ties, however tenuous, linking the Maya with southern Central America at an unexpectedly early time.

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Disintegration of Charged Liquid Jets: Results with Isopropyl Alcohol

Abstract. *Disintegration processes occurring with charged jets of isopropyl alcohol differ in several respects from results obtained with water. Although bimodal distributions of drop size shift to smaller diameters with increasing electrification for both liquids, the lower surface tension of the alcohol promotes the formation of secondary jets and a fan configuration not observed for water.*

Disintegration of charged liquid jets and subsequent droplet formation have been studied for more than a century. Peculiarities in the patterns of charged jet disintegration and drop formation have recently been described in some detail. Magarvey and Outhouse (*1*) investigated the breakup of thin water jets under combined electrical, molecular, and gravitational forces. With the onset of charging, the region at which the drops break off from the jet is affected first. With increased charging, the jet forms looping filaments characteristic of a length-extension instability. The drops formed after severing of the filaments have a different size distribution from those formed from an uncharged jet.

Huebner (*2*), using high-speed photographic techniques, found that charging of cylindrical jets of distilled water reduces the size of drops formed from the jets; the decrease in mean size increases with applied potential. Mean drop size decreases with increasing electrification of jets of isopropyl alcohol, partly as a result of the development of secondary jets from the primary jet. A new mode of jet disintegration in a fan-like configuration was observed.

The apparatus used to produce charged liquid jets has an insulated liquid reservoir in contact with one terminal of a conventional high-voltage source. A cylindrical, metal vessel coaxial with the jet collects the effluent and serves as the ground, or return, electrode. Two narrow slots, directly opposite each other in the sides of the collector, allow one to observe and photograph the jet breakup and droplet dynamics. A Wollensak Fastax high-speed motion picture camera synchronized with a microsecond pulse flash lamp permitted direct measurement of drop images in order to determine the sizes of drops formed from electrified jets (*2*).

The disintegration patterns of jets of isopropyl alcohol differ from those of water in that the former exhibit (i) extensive formation of secondary jets and (ii) the development of a fan configuration under certain electrical conditions (Fig. 1). For one of the jets of smaller diameter, the sausage instability, which results in drop formation from an uncharged jet (Fig. 1a), increases with slight electrification. Further electrification produces a kink instability (Fig. 1b). Still further increase in electrification results in the length-extension instability (Fig. 1c), which has also been observed with water jets of small diameter (*1, 2*). At the highest electrification possible without the onset of corona, the circular jet develops a fan-like configuration (Fig. 1d). The length-extension instability occurs with the smallest jets at low and intermediate flow rates and with jets of intermediate size at very low flow rates; it does not occur at all with the largest jets. The fan configuration developed at the higher applied potentials over the range of jet diameters used (0.372 to 1.25 mm).

Upon formation of the kink mode, very fine secondary jets develop at the positions of greatest lateral displacement. Full development of the fan is accompanied by an increase in the number of secondary jets, which form at the end of the fan. These secondary jets, which project outward at large angles with respect to the jet axis, are subject to the same instabilities as the primary jet and disintegrate quickly to form large numbers of small droplets.

As shown in Fig. 2, the reduction in the size of drops formed from the primary jet with increasing electrification and the formation of secondary jets cause a significant decrease in mean diameter compared to that in the case of the unelectrified jet. The orifice produces a bimodal distribution; both maxima usually shift toward smaller drop diameters with increasing electrification. As the applied potential V increased from 15 to 25 kv, and as the jet current i (measured between reservoir and collector) increased with the applied potential from 0.8 to 2.0 μa, the sizes of the larger drops changed very little but the relative number of larger drops produced decreased sharply, while the relative number of smaller drops produced increased commensurately. Many of these drops were smaller than the lower limit of resolution of the optical system. This accounts for the absence of a maximum in the distribution at small drop diameters.

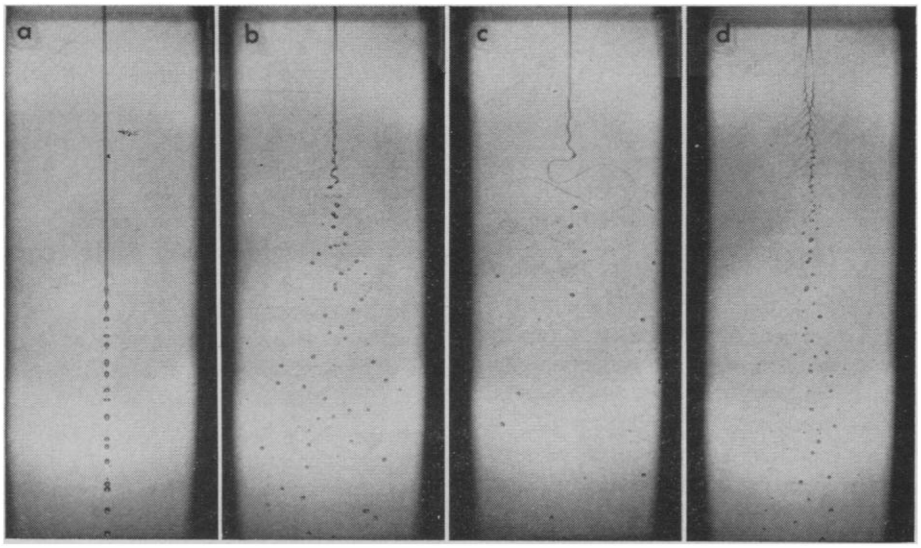

Fig. 1. Jet disintegration and drop formation with isopropyl alcohol. Jet diameter, 0.448 mm; flow rate, 0.448 ml/sec. (a) $V = 0$ kv, $i = 0$ μa; (b) $V = 5$ kv, $i = 0.12$ μa; (c) $V = 10$ kv, $i = 0.31$ μa; (d) $V = 25$ kv, $i = 2.2$ μa.

Relatively few secondary jets occur at a jet current of 0.8 μa; at 2.0 μa development of secondary jets is extensive. These large numbers of secondary jets account for the increased number of smaller drops. The failure of the diameter of the larger drops to decrease as jet current changes from 0.8 to 2.0 μa may result from charge being carried away by secondary jets. Using Lagrange's method, I have conducted an analysis of charged, cylindrical jets of distilled water and isopropyl alcohol. The length of the capillary wave that grows most rapidly, leading to jet breakup and drop formation, depends only on the potential at the surface of the jet for fixed jet and collector diameter. The wavelength, and consequently the drop size, decreases with increasing potential. Surface potentials may be about the same in cases where jet currents of both 0.8 and 2.0 μa are used if the secondary jets remove charge, thus decreasing the surface potential below the 25-kv applied potential and contributing to the jet current of 2.0 μa.

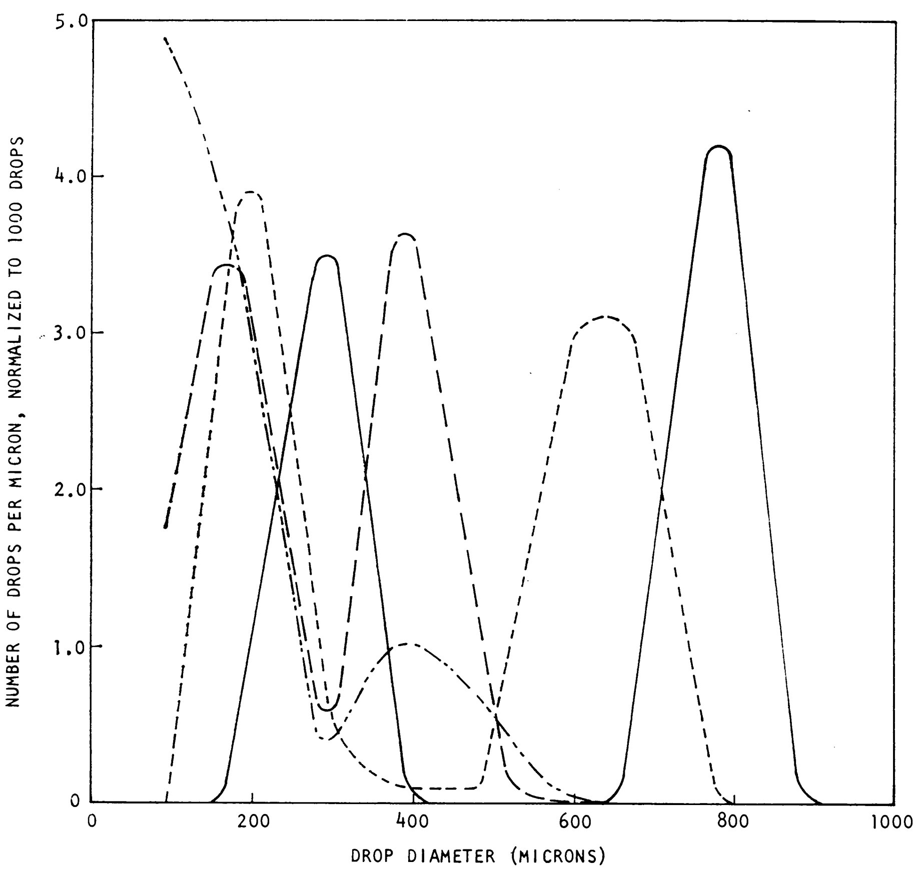

Fig. 2. Drop size distribution for various currents with isopropyl alcohol. Jet diameter, 0.394 mm; flow rate, 0.488 ml/sec; $i = 0$ μa, $V = 0$ kv (solid line); $i = 0.1$ μa, $V = 5$ kv (short dashes); $i = 0.8$ μa, $V = 15$ kv (long dashes); $i = 2.0$ μa, $V = 25$ kv (alternating long and short dashes).

Magarvey and Outhouse (*1*) have described length-extension instability as arising from opposing tendencies of surface tension and surface charge. The former minimizes surface free energy by decreasing the surface-to-volume ratio; the latter decreases the free energy of charging by increasing the surface area per unit volume. At sufficiently high electrification of the jet, the tendency for jet surface area to increase dominates, the surface free energy being supplied by the electrical power supply. The results reported here show that surface growth is not limited to length-extension instability; the fan mode is an alternative and competing manifestation of this surface growth. The tendency for the fan mode to dominate probably increases with decreasing surface tension. However, other liquid properties must affect the instabilities occurring as electrification of the jet increases.

Consistent with this view is the proposition that distilled water does not exhibit the fan configuration at potentials up to 25 kv because of its high surface tension. The substantially lower surface tension of isopropyl alcohol causes the fan configuration to be the dominant mode of instability at high electrification. At intermediate electrification, a length-extension instability appears in jets of low inertia, as shown in Fig. 1c.

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