

between larval stages may reduce the rate of seaward transport.

Although the rate of transport out of the estuary depends on the pattern of vertical migration of developing larvae and on the variance and magnitude of residual drift and tidal currents, many larvae are probably displaced seaward during development, each stage moving further toward the mouth of the estuary (14). Any behavior that would increase the magnitude of the up-estuary transport of the megalopae when they are ready to settle would be strongly favored. Female *Uca pugnator* are releasing their larvae at a time in the semi-monthly cycle of tidal amplitude and current velocity such that the megalopae experience maximum up-estuary transport when they are ready to colonize adult habitats.

Laboratory-reared *Uca pugnator* take about 18 days at 28° to 30°C to reach the megalops stage, and molt to the first crab after spending 3 to 15 days as megalopae (15). On the assumption that the megalopae will first be ready to settle after about 4 days, megalopae from clutches released 7 days before a spring tide would be ready to settle about 22 days later, during the next spring tides. If megalopae show the same patterns of vertical migration relative to the tide currents as stage one *Uca* larvae, then these megalopae would experience maximum up-estuary transport. Megalopae released near or during the spring tides would be ready to settle at the time of the neap tides. They would have a decreased probability of being carried to suitable substrates because of the smaller magnitude of their horizontal displacement by the neap tide currents.

This hypothesized behavioral adaptation of adults, which may be a general characteristic of the genus, should be viewed as complementary to behavioral adaptations of larvae that reduce transport out of the estuary. Both should increase the probability that larvae will reach substrates suitable for settlement.

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7. The crabs were marked by gluing a small piece of Scotch brand plastic tape onto their carapace with Duro Super Glue 3. The tags were num-

bered with a Sanford's black ink Sharpie Marker. During the first week of observation, counts of marked and unmarked animals revealed that about 80 percent of the females and 90 percent of the males in the enclosure were marked. I do not know whether the sex ratio inside the enclosure was an unbiased estimate of the true sex ratio of the adult population.

8. For absences where a male was last seen courting and next feeding, or feeding and then courting, I was unable to determine on which days of the absence he was and was not reproductively active. I have eliminated from this analysis all activity records with blanks of more than 2 days.
9. To estimate the dates of onset and termination of reproduction for cases where one or both were not observed, I added 1 day to the date on which a female was last seen feeding and subtracted 1 day from the date she was next seen feeding. The average lag between when a female was last seen feeding and when she closed with a male was 1.3 ± 0.28 days ($N = 23$). Six females who were seen to emerge with a ripe clutch and were allowed to naturally release their larvae were seen feeding on the day after larval release.
10. I was not able to judge whether females who disappeared after 9 August were reproducing since systematic observation ended on 17 August and

the mean length of absence when reproduction occurs is 14.5 days.

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16. I thank P. Feeny for guidance and encouragement and B. Christy for field assistance. Facilities were provided by the Mote Marine Laboratory (Sarasota, Fla.) and the Department of Entomology, Cornell University. I thank R. Stinnett for permission to work on Cayo Pelau and R. Buskirk and T. Vawter for comments on the manuscript. Supported by NSF grant BMS74-19937 for doctoral dissertation research.

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Particles in the Eruption Cloud from St. Augustine Volcano

A recent report by Hobbs *et al.* (1) describes airborne measurements of the effluents from St. Augustine volcano in Cook Inlet, Alaska. A series of eruptions began on 23 January 1976, and explosive activity continued intermittently until

about 18 February. The largest eruptions occurred during the period 23 through 26 January.

The measurements of Hobbs *et al.* were made during the period 8 through 18 February. They examined and ana-

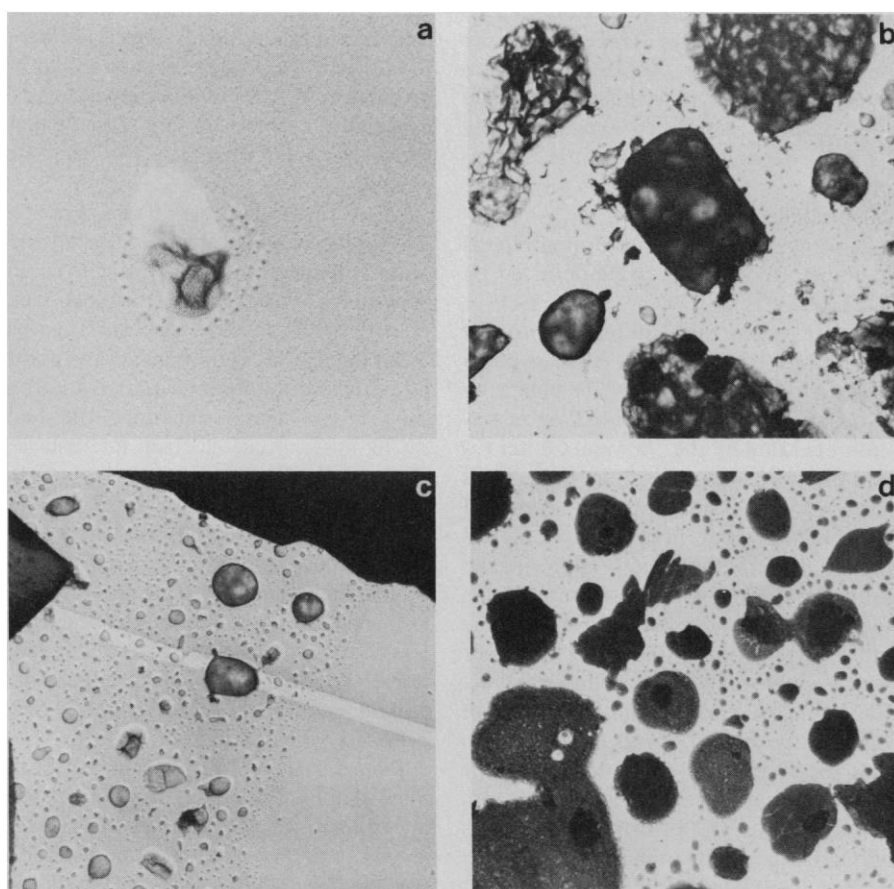


Fig. 1. Transmission electron micrographs of fume particles from the St. Augustine eruption. Distances across individual micrographs: (a) 1.9 μm ; (b) 4.1 μm ; (c) 13 μm ; and (d) 13 μm . The area in (d) had been allowed to evaporate in the electron beam. The other samples were gold-shadowed before being examined with the electron microscope.

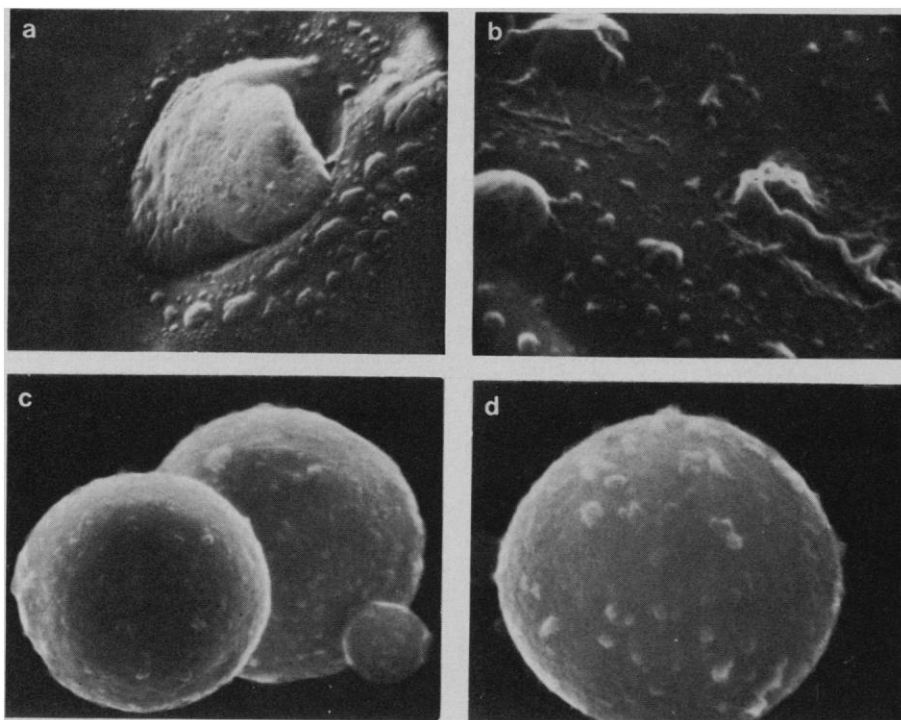


Fig. 2. Scanning electron micrographs of fume particles from the St. Augustine eruption. Distances across individual micrographs: (a) 11 μm ; (b) 5.5 μm ; (c) 8.2 μm ; and (d) 4.2 μm .

lyzed particles collected from the brown eruption clouds and from the white plume emitted between explosive phases, using scanning electron microscopy and an energy dispersive x-ray analyzer (EDXRA). Hobbs *et al.* tentatively concluded that the white plume they observed consisted almost entirely of volcanic ash, with very little S compounds or condensed H_2O on any of the ash particles. Furthermore, the ash particles from the explosion eruption clouds contained too little S to be detected by EDXRA.

We obtained quite different, but not necessarily conflicting, results for particles collected from the white plume by two impactors flown on an Electra aircraft operated by the National Center for Atmospheric Research. The collections were made on 1 February. The center of the plume was a few hundred meters higher than the summit of the volcano (altitude approximately 1300 m) and the temperature in the plume was, for the most part, about -10°C . One impactor was a single-stage device described by Cadle (2). Judging from the theory of Ranz and Wong (3), the theoretical diameter for 50 percent collection efficiency for a pressure drop of about 0.5 atm across the jet at 760 torr and 273°K is about 0.15 μm . The other impactor was a multistage cascade impactor described by Pilat *et al.* (4).

We obtained both transmission and scanning electron micrographs of the particles. Four of the former are shown

in Fig. 1. A large fraction of the particles appeared to be impure H_2SO_4 droplets. Particles collected by impactation consisting of a relatively large droplet surrounded by many small ones have been found, with no known exception, to be droplets of H_2SO_4 (5). This appearance is especially evident in Fig. 1a, which shows an isolated particle from St. Augustine.

Many of the particles had a wrinkled appearance, which was especially apparent in the transmission electron micrographs. Possibly the droplets were coated with a skin (organic?) which wrinkled as the liquid beneath evaporated, either as the fume drifted away from the volcano or in the vacuum of the shadowing system and electron microscope. Figure 1d differs from the other micrographs in Fig. 1 in that these unshadowed particles were allowed to evaporate and decompose in the electron beam of the microscope. All of the particles left a residue, an indication that the droplets contained dissolved material in addition to H_2SO_4 . A large percentage of the residues contained inclusions that were probably volcanic ash.

Figure 2 shows four scanning electron micrographs. Figure 2a, like Fig. 1a, was an isolated H_2SO_4 droplet. Figure 2b shows particles that were more or less wrinkled, similar to those in Fig. 1. An EDXRA attached to the scanning electron microscope revealed that S was the major detectable element in the particles, with smaller amounts of Si and Al.

These particles were probably mainly H_2SO_4 droplets containing liquid H_2O and traces of solid and dissolved material.

In addition to H_2SO_4 droplets, we also observed particles of volcanic ash. Many of these particles were spherical, and the surfaces were partially covered with sub-micron-sized particles which may have been impacted onto the larger spheres. The particles in Fig. 2, c and d, although morphologically similar, are chemically quite different. The EDXRA revealed that the particle in Fig. 2c contained primarily Al and Si with considerably smaller amounts of S, Ca, and Fe. However, the particle in Fig. 2d contained primarily Ca with lesser amounts of Al, Si, S, and Fe. The reason for these chemical differences is not known, but they could result from chemical differentiation within the lava or perhaps from interactions between the molten lava and the wall rock of the volcano.

On 20 February, the Electra again made several passes through the white plume but no impactor samples were collected. In contrast to the conditions on 1 February when the fumes in the plane were very unpleasant, on 20 February there was little or no odor of SO_2 in the plane. On both occasions the plume appeared to be of comparable opacity. The average SO_2 odor threshold concentration is about 2 to 3 mg m^{-3} (6). Hobbs *et al.* found an average gaseous S concentration, calculated as SO_2 , of about 0.07 mg m^{-3} in the brown cloud. The condition of the volcano at the time of these measurements may have been quite different from that during early stages of the eruption. Possibly the later explosions were largely phreatic, that is, caused by contact of groundwater with the magma.

On both occasions when we sampled, the "plume" actually consisted of two parts, namely, a dense white cloud above the crater which was extended by the wind into a long, tenuous, but somewhat darker-colored plume. We believe that, contrary to the findings of Hobbs *et al.*, the white cloud consisted largely of impure H_2O which had condensed on ash particles and which during early stages of the eruption contained considerable H_2SO_4 . Evaporation of the liquid H_2O as the cloud dispersed left a residue of the ash plus impure H_2SO_4 . A similar process, but without the H_2SO_4 , may have occurred in the white plumes sampled by Hobbs *et al.*

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The data of Cadle and Mroz (1), based on observations of St. Augustine volcano on 1 February 1976, provide an interesting comparison with the observations of Hobbs *et al.* (2) made between 8 and 18 February 1976. We believe that these two sets of observations are not in conflict, and that the differences were due to changes in the state of the volcano.

The first series of explosive eruptions (23 to 26 January 1976) removed much of the dome that formed during the 1964 eruption. These eruptions were followed by a relatively quiet period (during which Cadle and Mroz obtained their measurements). The next series of explosive eruptions (during which we made our measurements) began on 6 February, and intermittent violent eruptions continued until 13 February. This second series of eruptions produced a number of spectacular *nuées ardentes* (2, 3). A new dome began to rise from the crater on 11 February. This activity and the accompanying seismic signals (4) were probably the result of magmatic movement rather than the result of the intrusion of groundwater as suggested by Cadle and Mroz (1).

We began making our measurements during what may have been the early stages of a dome-building sequence. It appears that at this stage the volcano was emitting much less sulfur than during either the first series of explosive eruptions or the quiet period that followed. Ash samples collected at nearby Homer, Alaska, from the first series of explosive eruptions were richer in sulfur than the ash samples we obtained from the second series of eruptions.

In (2) we reported on some of the characteristics of the brown clouds produced by the explosive eruptions and the more continuous white emissions. Although the white emissions often resembled water clouds, in fact they consisted mainly of ash. The particles $> 0.1 \mu\text{m}$ in diameter in the white emissions had an elemental composition and a morphology similar to those of the ash particles in the

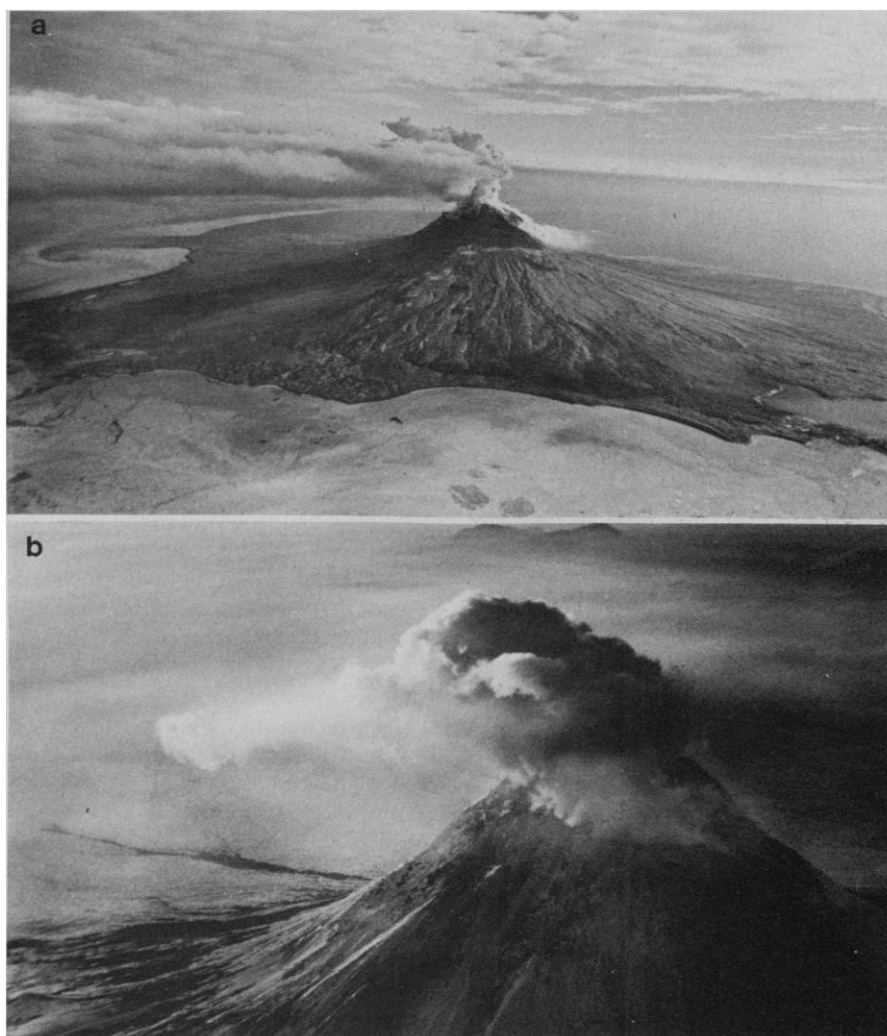


Fig. 1. (a) St. Augustine volcano on 18 February 1976. The white emissions discussed by Hobbs *et al.* (2) are those on the left. (b) St. Augustine volcano on 1 February 1976, illustrating the type of white cloud sampled by Cadle and Mroz. [Photos by E. Patterson, National Center for Atmospheric Research, Boulder, Colorado]

brown clouds. The different appearances of these two emissions were evidently due primarily to different particle size distributions (2). The brown clouds also had significantly lower concentrations of gaseous sulfur (0.07 mg m^{-3}) than the white emissions (0.2 to 3 mg m^{-3}). The white emissions that we studied generally contained no liquid water, were water-subsaturated, and did not evaporate (Fig. 1a).

The white clouds discussed by Cadle and Mroz (Fig. 1b) are quite different from the white emissions discussed in (2). The white clouds sampled by Cadle and Mroz (Fig. 1b) evaporated sharply within a short distance from the mountain (note the similarity of the white cloud in Fig. 1b to the small white cloud on the right of Fig. 1a, which is quite distinct from the main white emissions to the left in Fig. 1a). It appears that the white clouds sampled by Cadle and Mroz contained much more liquid water, less ash, and higher gaseous sulfur concen-

trations than the white emissions we studied. Apparently, from the observations reported in (1), such clouds also contain high concentrations of acid sulfate aerosol. Measurements obtained by us on 22 April 1977 at St. Augustine (a year after any major eruptions), in emissions similar in appearance to those in which Cadle and Mroz obtained their measurements, also revealed little ash and primarily acid sulfates for aerosol $> 0.1 \mu\text{m}$. In contrast, our earlier (February 1976) studies of the white emissions showed no evidence of acid sulfates in particles $> 0.1 \mu\text{m}$; however, the enhanced concentrations of particles $< 0.1 \mu\text{m}$ in these emissions (2) may have been due to sulfates produced by gas-to-particle conversion.

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Vision in Cubomedusan Jellyfishes

The report by Wald and Rayport (1) on visual physiology in alciopids complements the recent ultrastructural study (2) of the remarkable eyes of these worms. However, adding annelids to molluscs, arthropods, and vertebrates does not complete the list of animals with elaborate eyes (3). One outstanding example is found in the cubomedusan jellyfishes (4) of tropical marine waters, the eyes of which were described by the end of the last century (5, 6).

Cubomedusans have as many as 24 eyes located near the bell margin, and the most complex of these eyes have an epidermal cornea, spheroidal cellular lens, and upright retina (Fig. 1). The retina is composed of layers, corresponding to those of alciopids: a presumably sensory layer, a pigmented layer, a nuclear layer, and a region of nerve fibers. The cells described by Berger (6) as sensory contain a zone of pigment granules at the level of the pigmented layer and, in the sensory layer, long "axial fibers" which he tentatively identified as cilia and clearly illustrated with basal bodies.

There are roughly 11,000 sensory cells in the eye (7), a number comparable to that estimated for alciopids (1). Elongate pigment-filled cells (supportive cells?) extend between the sensory cells in sections from animals fixed in the light, and are partially withdrawn in sections from animals fixed in the dark; Berger interpreted these observations as evidence for a kind of adaptation to light and dark, similar to that in arthropodan and other complex eyes. Between the lens and the retina is a "capsule" through which narrow processes extend from the tips of the long pigment cells to the cells of the lens, features which Berger (6) speculated might be involved in accommodation for near and far vision.

Like alciopids, cubomedusans have been studied little (8, 9). They are agile and rapid swimmers; specimens only about 3 cm high have been clocked at up to 6 m per minute (10). They are active both by day and by night, and in the dark exhibit strong positive phototaxis (9, 10); they will orient accurately to the light of a match as much as 1.5 m away

even if the match is extinguished before orientation is completed (9). Their combination of speed and fine directional sensitivity to light might enable them to orient to luminescent prey at night. Larson (10) observed that cubomedusans attracted to a night-light "neither swam toward prey nor avoided obstacles," but the interesting possibility of image-forming vision under more normal conditions remains. Cubomedusans are unique among cnidarians in engaging in copulation (11); might the eyes be somehow involved in this behavior?

Cubomedusan eyes are so similar to the camera eyes of vertebrates and cephalopods that it would be surprising if studies of them, on the level now begun for alciopids (1, 2), did not yield valuable perspective and reveal some more elaborate functions than ordinary directional sensitivity.

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7. We arrived at this estimate by counting the sensory cells in figure 1 (cross section) of Berger (6); we then calculated the average density (3.3×10^5 cell/mm²) and estimated the retinal area, assuming that the retina occupies half of a spherical eye 145 μ m in diameter (measured inside pigment layer on figure 7 of Berger; see our Fig. 1).
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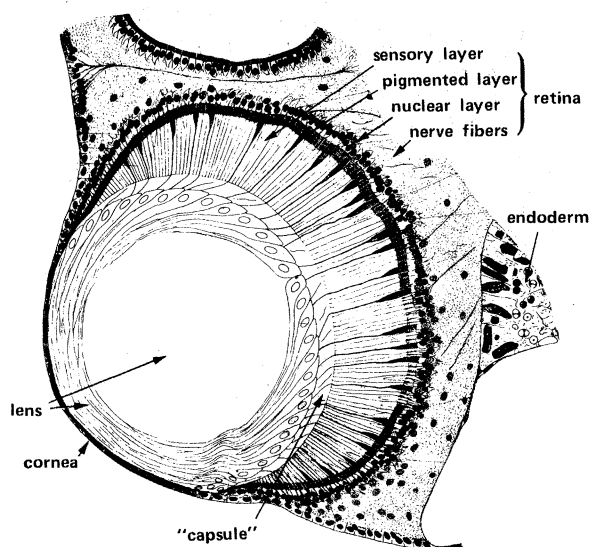


Fig. 1. Section of cubomedusan eye, from Berger (6, figure 7); relabeled. Part of the pigmented zone is drawn without pigment to reveal the basal bodies of the "axial fibers" that extend distally through the sensory layer. Berger states that in small specimens, the lens is cellular throughout; in larger adults, the central region often shows less distinct cellular features or even appears homogeneous, as drawn here.