quences, but also the fact that any wolf sequences have been lost from Clade I that points to an early date, says Dan Bradley, a molecular evolutionist at Trinity College, Dublin in Ireland. "That big clade is genetically and geographically diverse, and yet it is *all* dogs; there are no wolves in it. And that does not fit the idea of a single domestication of the dog only 14,000 years ago."

The absence of wolf sequences in Clade I also implies that once humans domesticated dogs, they interbred them with other dogs rather than seeking out fresh genetic stock in wild wolves, says Wayne. "It suggests that it takes some special skill to domesticate a wolf. If it were more easily done, you'd find more sequences similar to wolves in the dog clades." That fits an emerging pattern that the taming of wild animals is a fairly rare event requiring particular skill. For example, Bradley has shown that cattle were domesticated twice, while other research indicates that chickens were tamed only once.

Many scientists are quite skeptical of Wayne's estimated date, however. "It's a fascinating suggestion, saying that dogs are 10 times older than we thought," says Svante Pääbo, a molecular geneticist at the University of Munich in Germany. But he and others caution that the mitochondrial clock is none too reliable. "The date is very dubious—it's 135,000 years plus or minus about 300%," says O'Brien. Those who study the archaeological record are even more doubtful. Says paleoanthropologist Richard Klein of Stanford University, "There are no animal bones suggesting domesticated dogs—or domesticated anything—remotely approaching that time."

Wayne and his colleagues suggest that dogs aren't seen in the archaeological record until 14,000 years ago because they looked like wolves before that date. Dogs, they propose, may not have become morphologically distinct from wolves—becoming smaller and shorter muzzled—until humans themselves settled down in agricultural communities. That might mean that wolf bones from some early hominid sites are actually those of the protodog. If so, man's best friend began begging for food scraps about the time that modern humans emerged in Africa—which is highly unlikely, says Klein.

Dating questions aside, once humans succeeded in changing the wicked wolf into loyal Lassie, Wayne says, they apparently quickly developed a "large, ample pool" of dogs to interbreed—and to take with them wherever they went. "That's what this large, well-mixed and worldwide gene pool of dogs suggests," he says. That pattern implies that dogs and people do indeed share an ancient bond, agrees Klein. Besides the dog, only one other mammal has that rare combination of unusual genetic diversity and a widespread, well-mixed gene pool: humans.

–Virginia Morell

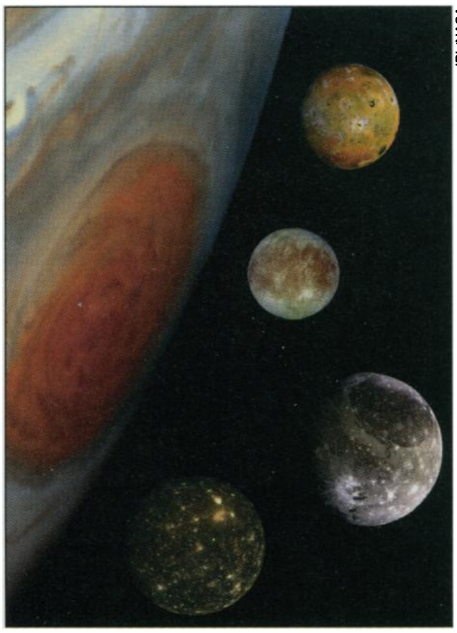
MEETING BRIEFS

From Clouds to Cores at the Spring Geophysics-Fest

BALTIMORE—When earth scientists gather for the semiannual meetings of the American Geophysical Union (AGU), the fare can range from earthquakes to evolution. This spring, more than 2000 researchers gathered here between 27 and 30 May. They heard diverse presentations that spanned the solar system, from the climate-altering effects of jet contrails in Earth's high atmosphere to the temperatures of the Jovian moons.

Jupiter's Coldhearted Moon

Any parent knows that siblings can be strikingly different, and the same is true in planetary science. Since the spacecraft Galileo began swooping by Jupiter's four largest moons in late 1995, researchers have become increasingly convinced that the three inside moons—Io, Europa, and Ganymede—are geologically complex bodies that even now harbor surprisingly fierce internal fires. But the outermost of the four moons, Callisto, seems to have been left out in the cold, according to the newest Galileo observations reported at the meeting and in a series of recent *Science* and *Nature* papers. Indeed, Callisto may never have warmed enough, even during its early years, to form the internal layering now evident in the other moons. Geologically, Callisto is dead and may never have been fully alive.



JPL/NASA

Family portrait. Jupiter's moons Io, Europa, Ganymede, and Callisto (top to bottom in this composite) have similar sizes but very different life histories.

Now, researchers are trying to explain these dissimilar biographies. Ganymede, for example, may have temporarily occupied an orbit in which Jupiter's gravity kneaded and warmed its interior, a process that is now warming Io and Europa. Callisto, meanwhile, may owe its deathly chill to its formation far from the mother planet's gravitational reach. But the evidence that Callisto was born cold is a puzzle. Because the birth of most moons and planets is thought to be accompanied by plenty of heat, Callisto's undifferentiated interior raises new questions about how such medium-sized bodies form. "The mystery is how you make Callisto this way in the first place," says planetary physicist William McKinnon of Washington University in St. Louis.

The first clue to the vibrant lives of some of these moons came in 1979, when the Voyager spacecraft sent back images of spouting volcanoes on Io. But judging the forces behind a moon's geologic activity can require a look inside, which planetary scientists are now getting from Galileo measurements of the moons' gravity and magnetic fields. A magnetic field like Earth's requires internal heating, usually early in the planet's history, to extract metal from rock and form a molten core, as well as enough lingering heat to keep that core churning to produce a magnetic field. In an overview at AGU, space physicist Margaret Kivelson of the University of California, Los Angeles, explained that the Galileo magnetometer picked up clear signs of internal fields at Io and at Ganymede, and a distinct magnetic signature at Europa that may be a weaker magnetic field. But Callisto clearly generates no magnetic field, meaning that any inner fires it had are now thoroughly damped.

What's more, Galileo's gravity data suggest that Callisto's fires never did flare very high. Such satellites first come together as well-mixed balls of ice and rock, but given enough heat, their constituents will melt and separate into a dense metallic core, a less dense rocky mantle, and a watery shell. Passing spacecraft can detect such layering by detecting subtle variations in a moon's gravitational pull, which reflect how much of the moon's mass is concentrated toward the center.

In the course of Galileo's seven close passes by Jupiter's four big satellites, team members led by John Anderson of NASA's Ames Research Center in Mountain View, California, looked for these clues. They monitored Doppler frequency shifts in the spacecraft's radio signal as the gravity variations altered the spacecraft's path. As Anderson and team member Gerald Schubert of UCLA summarized at AGU, all three of the inside moons show signs of layering, indicating past heating. But at Callisto, Galileo picked up no sure signs of layering. Callisto, said Schubert, looks like it is still a uniform mix of ice and rock.

Why is Callisto's interior so cold? As Schubert suggested at the meeting, the moon apparently formed too far from Jupiter's gravitational embrace. For example, Jupiter's gravity today rhythmically massages innermost Io, flexing and heating the moon's interior until part of it melts enough to feed its volcanoes. Jupiter can get this gravitational grip on Io because the moon is forced into an elliptical orbit by a gravitational interplay among the three inside moons. The same kind of gravitational massaging is also heating Europa, although more slowly.

The same process may explain Ganymede's internal heat, which had been a mystery because this moon, the third one out and a twin of quiet Callisto in size, is not now significantly heated by Jupiter. However, in last month's issue of *Icarus*, orbital dynamicists Renu Malhotra of the Lunar and Planetary Institute in Houston and Adam Showman of the California Institute of Technology (Caltech) identified a temporary orbital arrangement that the moons may have adopted, which would have heated Ganymede two to 30 times more than in previous estimates (*Science*, 19 July 1996, p. 311). That extra heat would have been enough to crank up Ganymede's magnetic field, and if it happened recently enough—say, a billion years ago—it could explain why the moon's internal magnetic dynamo is running today.

Theorists may understand why Callisto is so inactive today, but they are still coming to terms with the possibility that it was actually born cold. "If Callisto is indeed a uniform mix of ice and rock," says planetary physicist David Stevenson of Caltech, "that suggests rather little heating when the satellite formed. That's actually quite hard to do." In the standard formation scenario, moons like Callisto were assembled when smaller icy bodies called planetesimals crashed together. The heat from the impacts and from radioactive decay in the rock would have melted at least some of the material, allowing it to form separate layers. If Galileo's planned encounters with Callisto confirm the homogeneity of its interior, theoreticians will have to find a way for the moon to generate less heat during its formation or to lose heat faster. That's no small task, but it always has been hard to understand a heart that never warms.

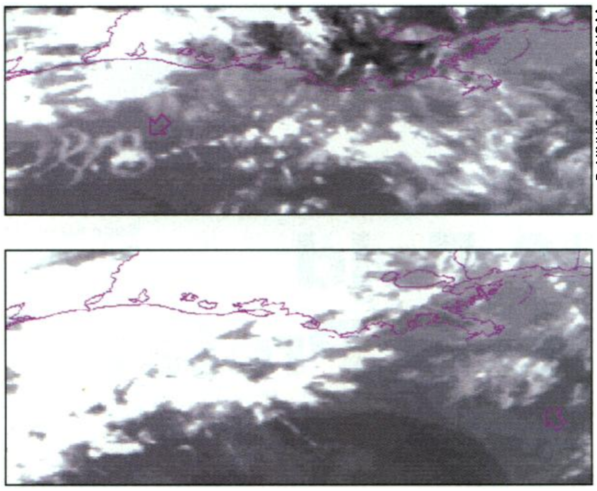
Contrails May Alter Climate

They look like harmless spider webs in the sky, but the strands of cloud spun out by high-flying jets could be the most visible sign of human influence on climate. Researchers have suspected for years that contrails, trails of condensation from jet exhaust that can slowly spread and evolve into natural-looking clouds, could be influencing climate across whole continents. But attempts at quantifying their effect—likely to be a warming, because high, thin clouds trap heat—have been foiled by the difficulty of tracking and measuring the ephemeral cloud trails. Data from new satellites are now helping fill in the picture, and the early results are sobering: A single contrail can persist for many hours and spread to cover tens of thousands of square kilometers.

That means the millions of contrails that crisscross the sky each year have at least a significant potential to alter climate in regions of heavy air traffic. "I'm convinced the global effect is small," says atmospheric scientist Ulrich Schumann of the German Aerospace Research Organization (DLR) in Oberpfaffenhofen, "but nobody can exclude that there's a regional effect over North America, Europe, and other major aircraft regions."

At the AGU meeting, atmospheric scientist Patrick Minnis of NASA's Langley Research Center in Hampton, Virginia, laid out the contrail researcher's conundrum. Researchers don't know how much of the sky is covered by contrails or how long individual contrails can persist. They do know that cloud cover has increased over some regions, and jets could be contributing. Over the United States, cloud cover is up about 5% since jet travel mushroomed several decades ago, and most of the new clouds may be in the form of cirrus, the thin, wispy cloud sheets that contrails can evolve into. The best estimate for western Europe has been only 0.5% to 2% extra cloud cover due to contrails, although Minnis suspects that's an underestimate.

At the meeting, Minnis offered new data on part of the puzzle: how long contrails can persist. By imaging large areas of clouds every 15 minutes in infrared wavelengths, he reported, the advanced Geostationary Operational Environmental Satellite (GOES-8) launched in 1994 has detected extremely long-lived contrails that ground-based and less detailed satellite observations had missed. For example, during the Subsonic Aircraft: Contrail and Cloud Effects Special Study (SUCCESS) conducted a year ago over the western United States, the satellite monitored a contrail from a DC-8 flying off the coast of northern California that persisted for at least 6 hours, spreading to cover 4000 square kilometers. GOES-8 also followed a figure-eight contrail of mysterious origin as it drifted across the Gulf of Mexico for 10 hours and eventually covered 20,000 square kilometers (see photos).



P. MINNIS/NASA LRC/NOAA

Telltale trail. A figure-eight contrail became unrecognizable after 3.5 hours off the Gulf Coast, but it persisted at least 10 hours.

The GOES observations are "solid evidence" that contrails can transform into extensive cirrus coverage and could explain some of the 5% increase in U.S. cloud coverage, says Minnis. Schumann is seeing similar contrail behavior in Europe. "I can confirm that contrails persist for several hours" over Europe, he says, on the basis of data from other U.S. satellites.

Climate-model simulations by Schumann and his colleagues also suggest that a 5% increase in contrail coverage would indeed drive a small regional warming. If—and it's a big if, Minnis cautions—the increase in U.S. cloud cover is mostly due to contrails, jet exhaust could be causing a regional warming as large as half that thought to be caused by increasing greenhouse gases—several tenths of a degree Celsius.

Such a contrail warming, although modest, could confuse the search for the distinctive pattern of regional warming expected to result from another human influence on climate: the rising levels of carbon dioxide and other greenhouse gases (*Science*, 16 May, p. 1040). All the same, says Schumann, contrails' climatic effect remains "an absolutely open question," because of the uncertainty in the total contrail coverage. Pinning down any warming left by jet planes will take more tracking of the cobwebs of the sky.

–Richard A. Kerr