FEATURES

DAWN OF THE DOG

An unprecedented collaboration may solve one of the greatest mysteries of domestication

By **David Grimm**, *in Columbus, Ohio*

A prehistoric dog is about to go to the dentist. Ardern Hulme-Beaman, a lanky 27-year-old Irish postdoc, pulls on a white facemask and lifts a small 5000-year-old jawbone from a cardboard box. He places a gloved hand over one of the molars and gently tugs from side to side until it pops out. The jagged top of the tooth is yellowish white, but the roots are dirty brown. Hulme-Beaman powers on a drill, and a circular blade screeches into a root. The scent of burning hair fills the air. "That's a good sign," he says. "It means there's DNA here."

Hulme-Beaman has spent the past 6 months traveling the world in search of ancient dog bones like this one. He's found plenty in this Ohio State University archaeology laboratory. Amid boxes stacked high with Native American artifacts, rows of plastic containers filled with primate teeth, and a hodgepodge of microscopes, calipers, and research papers, a few shoe and cigar boxes hold the jigsaw pieces of a dozen canines: skulls, femurs, mandibles, and vertebrae.

It's all a bit of a jumble, which seems appropriate for a field that's a bit of a mess itself. Dogs were the very first thing humans domesticated—before any plant, before any other animal. Yet despite decades of study, researchers are still fighting over where and when wolves became humans' loyal companions. "It's very competitive and contentious," says Jean-Denis Vigne, a zooarchaeologist at the National Museum of Natural History in Paris, who notes that dogs could shed light on human prehistory and the very nature of domestication. "It's an animal so deeply and strongly connected to our history that everyone wants to know."

And soon everyone just might. In an unprecedented truce brokered by two scientists from outside the dog wars, the various factions have started working together. With the help of Hulme-Beaman and others, they're sharing samples, analyzing thousands of bones, and trying to set aside years of bad blood and bruised egos. If the effort succeeds, the former competitors will uncover the history of man's oldest friend—and solve one of the greatest mysteries of domestication.

MORE ONLINE

For a video, quiz, and more, see http://scim.ag/k9science.

CHARLES DARWIN fired the first shot in the dog wars. Writing in 1868 in *The Variation of Animals and Plants under Domestication*, he wondered whether dogs had evolved from a single species or from an unusual mating, perhaps between a wolf and a jackal. Decades of speculation followed, until in the late 1990s, genetic analyses finally confirmed that dogs had descended from gray wolves. (The two share 99.9% of their DNA.)

Published by AAAS

Dogs have helped humans since prehistory. Here they accompany a caravan transporting salt in Tibet.

But just when and where this transition happened was a mystery. In 1977, scientists discovered a puppy buried in the arms of a human under a 12,000-year-old home in northern Israel, suggesting that dogs were domesticated in the Middle East, shortly before people took up farming. But later finds—skulls recovered from Russian caves and from ancient encampments in Germany—pushed canine origins back another 4000 years, indicating that dogs accompanied people in Eurasia while they were still hunters and gatherers.

Genetic investigations have only complicated the picture. A 1997 analysis of DNA from more than 300 modern dogs and wolves tallied genetic differences, aiming to use these as a measure of time since dogs began to diverge from their wolf ancestor. It concluded that dogs may have been domesticated as early as 135,000 years ago. Later studies argued for a more recent origin—less than 30,000 years ago—but the exact time and location remained unclear.

"There were lots of books written, and they all said something completely different," says Peter Savolainen, a geneticist at the Royal Institute of Technology in Stockholm. Savolainen had become interested in the topic in the early 1990s as a master's student in a government forensics lab, where he set up the world's first canine DNA database to help police with two unsolved murders. Dog hair had been found on the bodies, and by collecting genetic material from 100 canines across the globe, he helped the officers determine the type of dog the murderer owned.

Savolainen knew that DNA had been used to pinpoint Africa as the place where modern humans emerged, and he wondered if a similar approach could help him home in on the birthplace of dogs. "Already in our small database, I saw a pattern," he says. East Asian breeds were more genetically diverse—a hallmark of more ancient origins. As Savolainen continued to build his database, the pattern remained. In 2009, he published a genetic analysis of more than 1500 dogs from around the world, concluding that the animals had likely arisen in a region south of China's Yangtze River less than 16,300 years ago—a time when humans were transitioning from hunting and gathering to rice farming. These early canines, his team speculated, may have been raised for meat. "The data are very clear and distinct," he says. "For me, the basic question is solved."

Not for Robert Wayne, an evolutionary biologist at the University of California, Los Angeles. The elder statesman of canine ge-

netics, Wayne began working on dog DNA in the early 1980s, when genetic sequencing was still in its infancy. Like Savolainen, he's interested in where dogs came from. But the two have come to very different conclusions and have been sparring in papers and the press for more than a decade.

That's largely because Wayne thinks looking at modern DNA is a mistake. "We have this image of dogs living in our homes and going on walks with us," he says. "But that's not the way it was in the past." Dogs regularly interbred with wolves and canines from other regions—especially in China, he says, where traffic along major trade routes likely brought in breeds from Europe, the Middle East, and elsewhere in Asia. Any genetic diversity in modern Asian dogs, he says, may simply be a result of all of these far-flung animals mating. "It would be like concluding that humans arose in the United States because there's so much genetic diversity here."

Instead, Wayne focuses more on ancient DNA, hoping to peer back to a time when dog populations were relatively isolated from one another. In 2013, he and his colleagues published the most extensive analysis of ancient dog and wolf genomes to date. Comparing the DNA of 18 dog- and wolflike bones from Eurasia and America to that of modern dogs and wolves from around the world, the study found that the DNA of ancient dogs most closely matched that of European wolves, and the DNA of today's dogs most closely matched that of ancient wolves.

That led the group to conclude that dogs evolved from a now-extinct group of wolves in Europe, somewhere between 19,000 and 32,000 years ago. These early dogs may have resembled Siberian huskies on steroids—their hunting prowess and ability to carry heavy loads a boon to ice age humans as they pursued mammoths and other large game across a frigid continent.

Savolainen pounced on the study, calling it "geographically biased" in a 2013 story in *The New York Times,* because Wayne's group hadn't used any samples from Southeast Asia. "It's like studying the geographical origins of humans without including a single sample from Africa," he says. Wayne shot back, saying he hadn't included ancient specimens from China because there were none—a fact, he said, that cast further doubt on the view that dogs had originated there. "I think we've reached an impasse," Wayne says. "We don't interact much."

Greger Larson holds a wolf skull at the Oxford Museum of Natural History (*top*). Ardern Hulme-Beaman (*bottom*) examines an ancient dog jawbone (*middle*).

PHOTOS: © JOHN CAIRNS (3); (PREVIOUS PAGE) © KAZUYOSHI NOMACHI/CORBIS

Geneticists aren't the only ones brawling. In 2009, paleontologist Mietje Germonpré reported finding an unusual skull in the archives of her museum, the Royal Belgian Institute of Natural Sciences in Brussels. Though the scientist who had originally unearthed the skull from Goyet Cave in southern Belgium pegged it as a wolf cranium, Germonpré's measurements indicated that it belonged to a dog. Radiocarbon dating revealed that the skull was 32,000 years old—so much older than other ancient dog remains known at the time that it could have finally stamped a time and place on canine beginnings.

Critics chomped, calling Germonpré's analysis "premature" and "misleading." They said the specimen, like some other ancient putative dog skulls, could merely be a strange-looking wolf. Germonpré responded that the creature may have been an early dog that didn't give rise to today's canines—a primitive attempt at domestication that hit a dead end. "It's a very combative field," she sighs. "More than any other subject in prehistory."

ENTER GREGER LARSON and Keith Dobney. The two had met in the early 1990s in Turkmenistan, where Dobney and a large group of other British archaeologists were excavating an early farming village. Larson—fresh out of college in California—showed up unannounced, wearing a baseball cap and loafers. The archaeologists, in their floppy hats and scruffy trousers, "thought he was just another preppy American," Dobney says. Yet Larson quickly impressed the scientists, asking a volley of incisive questions about their work. "It was a bit irritating, but his enthusiasm was infectious," Dobney says. Within a few days, Larson was shotgunning beers with his new pals.

The two began working together a few years later when Larson was a Ph.D. student at the University of Oxford and Dobney was back at the University of Aberdeen, both in the United Kingdom. Both were interested in the domestication of the pig—an animal that, like the dog, had played a crucial role in early human history but whose origins were murky. Their initial work, based on modern DNA, suggested that humans had independently domesticated wild boar in several locations. But when they combined ancient DNA with a relatively new technique known as geometric morphometrics—which involves taking thousands of measurements of bones to see how their shapes differ between individuals—they discovered that a long history of trading and interbreeding had created the impression of numerous domestication events when there were likely only one or two.

A gray wolf.

PHOTO: © MARC MORITSCH/NATIONAL GEOGRAPHIC CREATIVE/CORBIS

How the wolf became the dog

By **David Grimm**

Scientists who study canine origins seem to fight about everything: where dogs arose, when this happened, and even the best way to find these answers. But there's one thing most of them agree on: *how* dogs became domesticated. Still, it's taken almost a century to get here, and the details are still emerging.

In 1907, the English scientist Francis Galton suggested that dogs first entered our lives when our ancestors nabbed some wolf pups, brought them back to camp, and raised them as pets. If you've ever seen a baby wolf, with its big eyes and oversized ears, the idea doesn't seem so far-fetched—and, indeed, Galton's hypothesis reigned for decades. But scientists eventually realized that domestication is a long, messy process that can take hundreds or even thousands of years. These early humans may have started with a cute pup, but they would have ended up with a wild animal.

So what did happen? Most experts now think dogs domesticated themselves. Early humans left piles of discarded carcasses at the edges of their campsites—a veritable feast, the thinking goes, for wolves that dared get close to people. Those wolves survived longer and produced more pups—a process that, generation by generation, yielded ever-bolder animals, until finally a wolf was eating out of a person's hand. Once our ancestors realized the utility of these animals, they initiated a second, more active phase of domestication, breeding early canines to be better hunters, herders, and guardians.

A massive collaboration that's trying to figure out where and when dogs emerged (see main story, p. 274) has found some intriguing insights into the second phase of dog domestication. A comparison of thousands of ancient dog and wolf skeletons, for example, has revealed flattening of the dorsal tips of ancient dog vertebrae, suggesting that the animals hauled heavy packs on their backs. The team has also spotted missing pairs of molars near the rear of the jaw in ancient dogs, which may indicate that the animals wore some sort of bridle to pull carts. These services, in addition to dogs' hunting prowess, may have proved critical for human survival, potentially allowing modern humans to outcompete our Neandertal rivals and even eventually settle down and become farmers.

Now, a study on page 333 helps explains how man and dog took the next step to become best friends. Takefumi Kikusui, an animal behaviorist at Azabu University in Sagamihara, Japan, and his colleagues have found that when dogs and humans gaze into each other's eyes, both experience a rise in oxytocin—a hormone that has been linked to trust and maternal bonding. The same rise in oxytocin occurs when human mothers and infants stare at each other, suggesting that early dogs may have hijacked this response to better bond with their new human family.

The oxytocin study and the skeletal data from the new collaboration go beyond clarifying the origin of the family pet, says collaboration leader Greger Larson, an evolutionary biologist at the University of Oxford in the United Kingdom. "The more that we know about the process of how dogs became associated with people, the more we learn about the origins of civilization." ■

A dog skull sits on a disk, as scientists prepare to photograph it for geometric morphometrics.

"When all these dog papers started coming out, we got really frustrated," says Larson, now an evolutionary biologist at Oxford. "We felt we had done more with pigs." He thought that Wayne hadn't accurately distinguished between ancient wolf and dog bones and that his samples were too geographically limited. Yet he also faulted Savolainen for trying to use modern DNA as a window into the past. "It's like a giant tomato soup with just one color," he says. "You can't go back and figure out what the ingredients are."

Larson and Dobney wanted to take a lesson from their pig work—analyzing as many samples as possible from as many places as possible and combining ancient DNA analysis with geometric morphometrics. But in order to do this, they were going to have to bring everyone together.

Money proved a great motivator. Though dogs loom large in the public consciousness, they don't tend to loosen the purse strings of funding organizations. As a result, many scientists work on them as only a hobby or side project, piggybacking on funding from other grants. But Larson and Dobney made a strong case to European funding agencies in 2012, arguing that the domestication of dogs set the stage for taming an entire host of plants and animals. "We said, without dogs you don't have any other domestication," Larson says. "You don't have civilization."

The approach worked. The duo secured $3 million and began calling people up. "We told them, 'We're going to do this. We have the finances. We want you on board,' " Larson says. His personality helped. "Everybody likes him," Dobney says. "People don't see him as a rival." Larson also took ego out of the equation. "I told everyone, 'I don't give a shit where I am as an author on these papers—I just want to get them out.' "

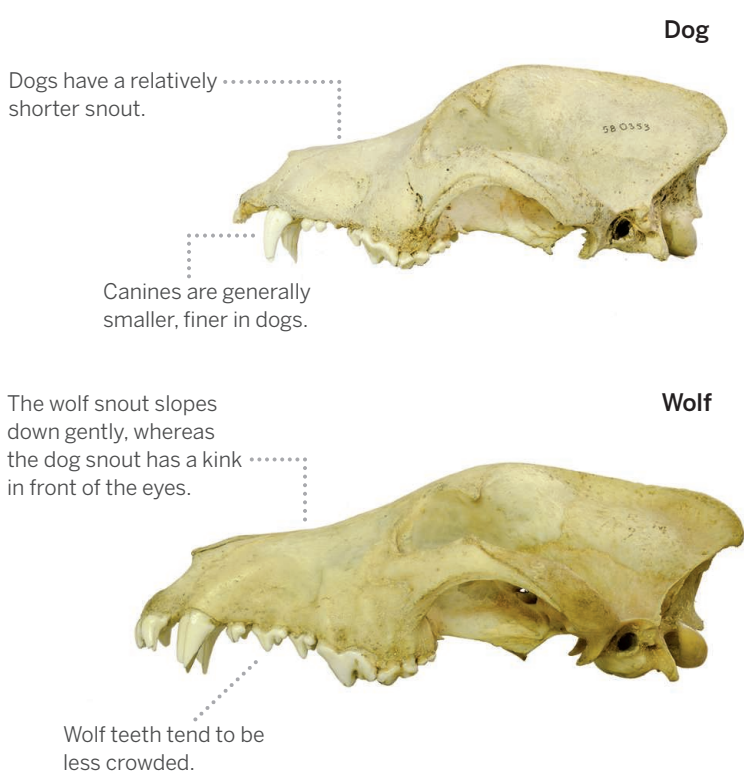
By the end of 2013, Larson and Dobney had attracted 15 collaborators, including Wayne, Savolainen, and Germonpré. In a 2-day conference in December, they hammered out the details of the project. "You could feel the tension in the room," Dobney recalls. But Larson soothed the small crowd. "Everything is water under the bridge," he told them. "We all have a stake in this."

Savolainen was intrigued by the opportunity to delve into new data sets. "There's always more to learn," he says. And Wayne was excited to analyze more samples. "Greger won the trust and confidence of a lot of people," he says. "That's a real skill." Now, they just had to get their hands on thousands of bones.

BACK AT OHIO STATE, Hulme-Beaman is drilling into a second dog molar, but this time he seems nervous. The tooth has a hairline crack, and he's worried it will fracture or explode: precious DNA lost in the dust, an irreplaceable museum specimen destroyed. But he gets lucky; the root saws clean off, and the rest of the molar remains intact. Hulme-Beaman plugs

Wolf versus dog

Traditionally, researchers used the traits below to distinguish wolves from dogs, but geometric morphometrics may reveal new nuances.



PHOTOS: (TOP TO BOTTOM) © JOHN CAIRNS; ARDERN HULME-BEAMAN, PHOTOGRAPHED AT THE SWEDISH MUSEUM OF NATURAL HISTORY (2)

the tooth back into its mandible and slots the root into a tiny Ziploc bag, where it will be shipped to the United Kingdom for genetic analysis. "That's about as good as it can go," he exhales.

The postdoc has made 11 trips as one of the dog collaboration's two main sample hunters, traveling from his home base at the University of Aberdeen to other universities, museums, and even private collections. "I'm on a plane or train every 2 to 3 weeks," he says. He's probed wolf skulls in Serbia, cradled dog bones in Sweden, and scoured the archives of the Smithsonian Institution in Washington, D.C. Most of the destinations come from scanning the scientific literature, talking to experts, and putting up posters at professional and amateur archaeology conferences. "There's a huge amount that's hidden in desk drawers," he says.

Hulme-Beaman is at Ohio State because of a call Larson received from Paul Sciulli, a retired physical anthropologist who heard about the collaboration. He told Larson he had access to a bunch of ancient Native American dogs, some of which he had dug up himself in unexpected places. "There are sites where you find nothing," says Sciulli, who has swung by to check on Hulme-Beaman's progress. "No houses, no signs of village life. Just graves. And it's just people and dogs." Most of the dogs were about the size of beagles, and some were buried with their owners, one under a person's arm. "These weren't wild animals," he says. "They were part of the family."

Sciulli watches as Hulme-Beaman moves on to another specimen, gingerly removing a yellow-brown cranium the size of a pineapple from a plastic bag. He places the sample on a record-size disk, beneath a camera attached to a jointed mechanical arm. Then he slowly rotates the disk, snapping a picture every 2 seconds as the images appear on a nearby laptop. "We're tricking the computer into thinking that we're walking around the object," he explains. By the time the disk has done a 360, he has taken more than 200 shots, and a three-dimensional rendering of the skull pops up on the screen, rotating to expose every nook and cranny—a carbon copy cranium Hulme-Beaman can bring anywhere.

The computer can now do something no archaeologist can: perform geometric morphometric analysis of the skull. The thousands of measurements it will take will go far beyond mere length and width to determine actual shapes: the precise circlets of eye sockets, the jut and jag of every tooth. Ancient DNA, Hulme-Beaman says, can tell you where an animal came from, but only such morphometric data can show you domestication in progress—the sharper angling of the snout, for example, that took place as wolves morphed into dogs.

"For the first time, we're going to be able to look at some of these strange skulls like the Goyet skull and figure out how strange they really are," he says. "Are they wolves becoming dogs, or are they just unusual wolves?" Combining the two approaches, he says, should allow the collaboration to home in on just where dogs came from—and when this happened.

"Archaeology is storytelling," Hulme-Beaman says. "I think we're going to be able to tell a great story."

The skeletons of a human and dog (*upper left*) discovered underneath a 12,000-year-old home in northern Israel are early evidence of the human-canine bond.

PHOTO: © THE UPPER GALILEE MUSEUM OF PREHISTORY

AT THE END OF THE DAY, Hulme-Beaman packs up his laptop and samples and prepares for his next trip, likely to Istanbul. Sciulli suggests a detour, mentioning a museum in Cleveland that has "hundreds of bones" from a local site; he says he can put the curator in touch. Hulme-Beaman looks tired, but he smiles. "Sure," he says, "give me his number."

A continent away, Larson and Dobney have continued to make phone calls. Their collaboration has now swelled to 50 scientists from around the world—experts on dogs, domestication, zooarchaeology, and genetics. Larson estimates that the team has analyzed more than 3000 wolf, dog, and mystery specimens so far, and he expects the group to submit its first paper this summer. "I've been really encouraged by how everyone has been getting along," he says. "We have a lot more in common than we thought."

Larson feels confident that the work will solve the mystery of dog domestication once and for all, though some experts aren't so sure. Just throwing a lot of data at an enigma won't necessarily unravel it, warns Richard Meadow, the director of the zooarchaeology laboratory at Harvard University's Peabody Museum. "The more samples you get, the more complicated things get." And Hulme-Beaman points out that even if there is an answer, it's likely to disgruntle some of the collaborators.

Still, the formerly warring camps seem sanguine. "I'm willing to accept a different result," Savolainen says. "If I'm wrong, it will be a bit embarrassing," he laughs, "but science is about trying to find the truth." Wayne agrees. "Even if what we find contradicts my hypothesis, I'd be very happy," he says. "I just want an answer." ■