IT CAME FROM OUTER SPACE
Beneath the fertile soils of the small town of Ames lies a geological imprint so unique that it only could have been created by a force from out of this world. When a meteorite crashed into that section of Earth 450 million years ago, it left in its wake a crater rich with oil and a fascinating scientific puzzle for future Oklahomans to unravel.

WITH A POPULATION OF 200, IT MAY SEEM UNLIKELY THAT AMES HAS GAINED INTERNATIONAL ATTENTION FROM THE SCIENTIFIC COMMUNITY. GIVEN THAT THE TOWN SITS ATOP ONE OF THE MOST INFORMATIVE GEOLOGICAL DISCOVERIES OF MODERN TIMES, THIS ASSERTION SEEMS LESS FAR-FETCHED.

WOUND

PASSING THROUGH THE small agricultural community of Ames in southeast Major County, one would hardly suspect that the quiet pastoral stretch of land was once the site of a catastrophic, earth-shaking event the effects of which would be felt for eons to come. However, some 450 million years ago in this very spot, a celestial body violently struck the earth, creating one of Oklahoma's most unique geological phenomena: the Ames astrobleme.

Astroblemes, or meteorite impact craters, are nothing new. In fact, given that some of them date back nearly two billion years, it would be difficult to find anything much older. The first known bona fide impact crater in the world, Meteor Crater in Arizona, was haphazardly discovered while being mined for iron in 1903, though its cosmic origin was not scientifically proven until 1960. Since then, the existence of more than 150 terrestrial impact craters has been confirmed across the globe.

The Ames astrobleme is not nearly the oldest of such features; nor is it among the largest. Rather, the structure's importance stems as much from its economic significance as its geological value. The Ames astrobleme holds one of the richest oil and gas reserves in the country, and its exploration has led to a new way of looking at petroleum geology. It also helped build the energy company that produced Oklahoma's latest billionaire.

BY JAKE ADAMSON | PHOTOGRAPHY BY REBEKAH WORKMAN

EARTH ILLUSTRATION, PETE TURNER/GETTY IMAGES; METEOR, KYLE GANDY

> "THE VERY FIRST MAP WE PRINTED OUT, WE SAW THIS ANOMALY OF THE AMES HOLE," SAYS HAMM. "OUR EXPLORATION MANAGER AND I LOOKED IT OVER, AND WE BOTH THOUGHT THE SAME THING: THIS LOOKS LIKE AN ASTROBLEME."

Harold Hamm is founder and CEO of Continental Resources; he and his team discovered the astrobleme.

WILD CHANCES

Harold Hamm began his career in the oil business from the ground up.

"I started with an oil-field service company and began work from the service side, cleaning up stock tanks—the grunge work," says Hamm. Now listed at number 42 on the Forbes 400, Hamm is president of Continental Resources based in Enid, a fast-growing petroleum exploration and production company that took its stock public in May 2007.

In 1967, Hamm ventured into the exploration side, founding the company that would later become Continental Resources. He drilled his first wildcat well in 1971 and met with success.

"Luckily, the prospect I dreamed up worked," says Hamm. "We found a nice little field, and the rest is history."

The Ames community plays a large role in that history. Hamm lived in Ringwood, near Ames, during his company's fledgling years. His fondness for the Ringwood-Ames area grew at the same rate as his well count.

"We had a lot of wells in Major County," says Hamm. "We wanted to know our backyard really well."

Wells began producing oil in the Ames astrobleme formation in 1990, but the quantities produced were considered marginal. Early guesses about the nature of the depressed area of land resulted in a foregone conclusion that the large indentation was a naturally occurring graben.

In 1988, determined to find more reserves close to home, Hamm began a program to look for deeper developments in the area. Using a computerized mapping system capable of detailing large tracts of land at one time, Hamm's exploration team began to notice something strange in the Ames area's geology: a circular formation of rock buried deep below the surface.

"The very first map we printed out, we saw this anomaly," says Hamm. "Our exploration manager and I looked it over, and we both thought the same thing: This looks like an astrobleme. We went from there with that thought and shot forty-three miles of 2-D seismic lines across it to confirm what it looked like."

Two years later, Hamm organized an exploration team tasked with learning everything about the anomaly they called the Ames Hole. To round out his exploration team, Hamm consulted Richard Donofrio, a geologist who ten years previously had written a paper on the possibility of oil production in impact craters formed in granite rock.

Donofrio's background in astrogeology had led him to work on the Viewfield anomaly in Saskatchewan, Canada. Viewfield, which was discovered and drilled for oil in 1969, was a geological anomaly. It had the appearance of an impact crater but lacked evidence of shock metamorphism—changes in minerals due to extreme heat and pressure—the defining characteristic of astroblemes. Although the Viewfield anomaly's status as a crater was unconfirmed, it was relevant to the Ames team because of its petroleum reservoir.

The exploration team, led by Hamm and Jack Stark, Continental's vice president of exploration, examined every possible aspect of the Ames Hole in order to confirm its classification as an astrobleme. Early measurements showed that the Ames anomaly was buried beneath more than nine thousand feet of sediment with a diameter of nearly eight miles. No evidence of the meteorite that struck the area could be found; it vaporized on impact.

"We had a couple of core samples from the crater, plus the gravity, magnetics, and a structure-type map," says Donofrio, now the company geologist for Parwest Land Exploration in Oklahoma City. "Shocked quartz also was found in the feature. It was primarily the diagnostic features of the quartz and the overall geology that led to the conclusion that it was from an impact structure."

Shocked quartz, which has a different microscopic structure than normal quartz, has been found only in impact craters. The intense

TAKE OUR WORD FOR IT: A GLOSSARY

Any discussion of astroblemes requires a lesson in Geology 101.

ANOMALY: a rock formation that resembles an astrobleme but has not been confirmed as such

ASTEROID: a small celestial body that orbits the sun with a diameter of a few to several hundred kilometers

BASEMENT: the complex igneous or metamorphic layer of rocks that lies beneath a layer of more recent, softer sedimentary rocks

BRECCIA: a coarse-grained sedimentary rock made of sharp fragments of rock and stone cemented together by finer material

EJECTA: ejected matter, such as that from a volcanic eruption or a meteorite impact

GRABEN: a valley or depression between geological faults

LITHIFY: to change from loose sediment into solid rock

METEOR: an incandescent streak in the sky formed when a meteoroid enters the Earth's atmosphere

METEORITE: a piece of a meteoroid that has reached the surface of the Earth from outer space

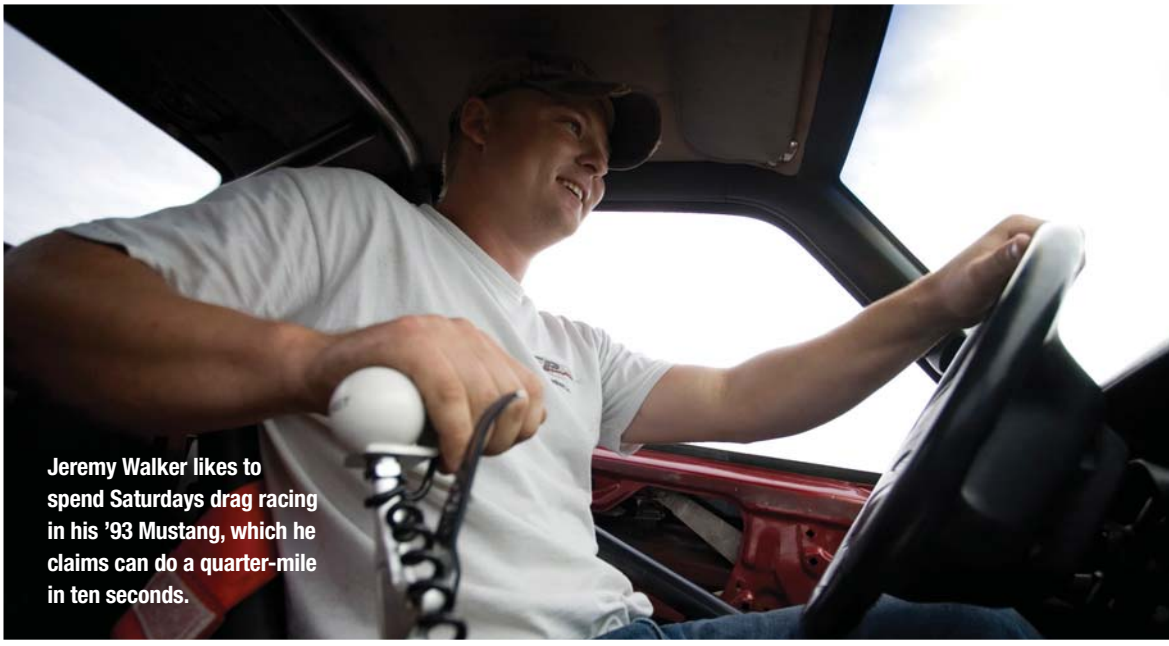
METEOROID: a solid body moving in outer space that is larger than a speck of dust but smaller than an asteroid

SYNCLINE: a fold of rock layers that slope upward on both sides of a common low point.

LIFE IN THE CRATER
Ames Astrobleme Museum caretaker Bob Mackie, Ames city manager Jim Johnson, and museum project manager Bert Mackie

JAKE ADAMSON

Six-year-old Mickenzie Turner plays in her tree house.



Jeremy Walker likes to spend Saturdays drag racing in his '93 Mustang, which he claims can do a quarter-mile in ten seconds.

Under the watchful eye of his dad, three-year-old Baylin Bode casts his line.

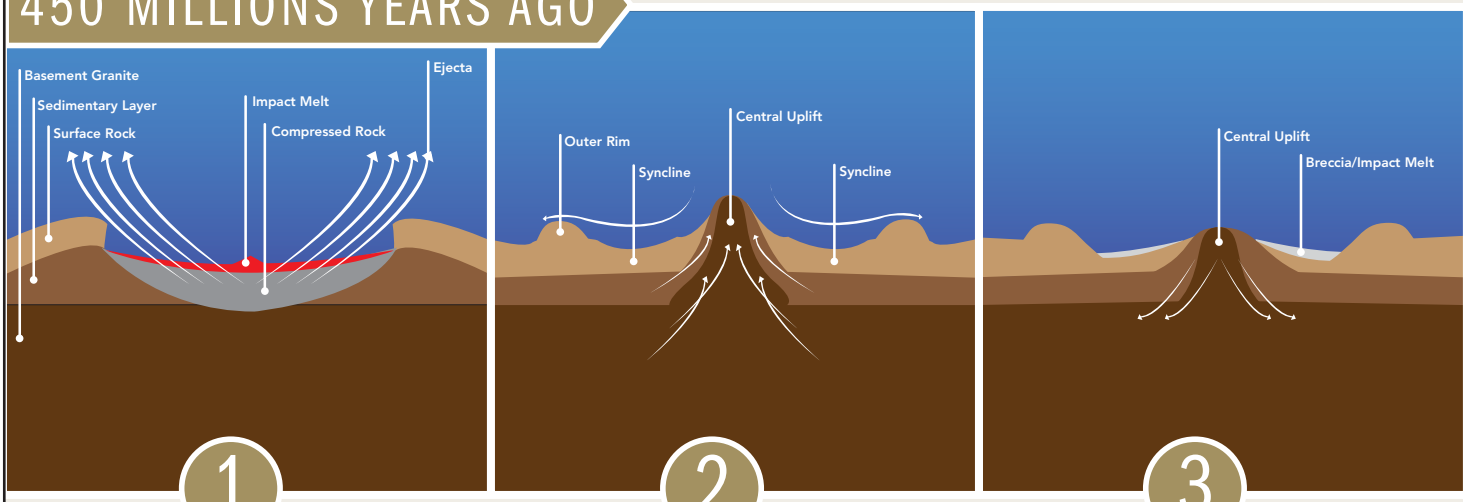
JAKE ADAMSON

Home to 200 residents, Ames is a quiet community in northwest Oklahoma.

HOW IT HAPPENED

The Ames astrobleme was formed in a matter of seconds, but it made a lasting impression that withstood the test of time.

450 MILLIONS YEARS AGO



ILLUSTRATIONS BY KYLE GANDY

1 At the point of impact, rock layers are compressed as the meteorite excavates the crater, sending ejecta into the air. Intense heat and pressure are applied.

2 The impact pushes rock away from the center, creating the outer rim. The center of the impact site rebounds, creating a central uplift encircled by synclines.

3 The central uplift collapses and forms the inner ring as the uplift material spreads outward. A blanket of breccia and impact melt covers the surface.

pressure and heat required to deform the rock's crystalline structure cannot be replicated using any other natural process.

Once Hamm knew what he was dealing with, a drill stem test was performed at the well site known as the Gregory, one of the astrobleme's most productive wells.

"We drilled into the Arbuckle formation at 9,200 feet and tested it, and it flowed two hundred barrels an hour in the first test," says Hamm.

Since the first test was performed in 1991, the wells within the Ames astrobleme structure have produced more than 17.5 million barrels of oil and 80 billion cubic feet of natural gas. The ultimate recovery from the field is expected to be more than 25 million barrels of oil and 100 billion cubic feet of gas. To date, the gross production values of the Ames field exceed $120 million.

"If you had a well that made 100,000 to 150,000 barrels out there, that would be very exceptional, much less millions of barrels like the Gregory, Wayne, and a few other Ames site wells," says Hamm. "Those were phenomenal wells, not exceptional."

The Ames Hole has outperformed the Viewfield anomaly and the Red Wing Creek astrobleme in North Dakota, two of the few known oil fields in North America located in anomalies or craters. Ames produced 2,600 barrels of oil per day at its peak in 1994, whereas Viewfield and Red Wing Creek produced 575 and 960 barrels a day, respectively.

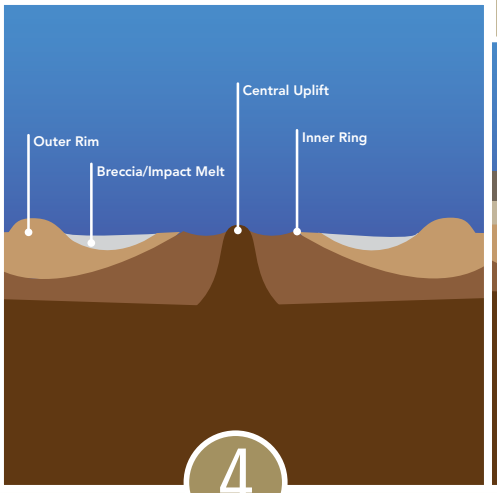
"Astroblemes are fascinating structures," says Donofrio. "They produce their own reservoir rock, and if you catch it in the right spot at the right time, you've got a heck of an oil field."

POINT OF IMPACT

The word astrobleme comes from the Greek root words *astro*, meaning "star" and *blema*, meaning "wound." Astroblemes, therefore, are scars on the surface of the earth. Just as flesh wounds leave behind scar tissue as they

Richard Donofrio displays a melt rock sample containing shocked quartz.

{ THE CENTRAL UPLIFT, ALONG WITH THE RIM, IS WHERE THE RICHEST OIL RESERVES ARE FOUND. AT AMES, THE METEORITE'S IMPACT WAS SO GREAT THAT IT DISTURBED BASEMENT GRANITE LYING DEEP BENEATH THE SURFACE. }



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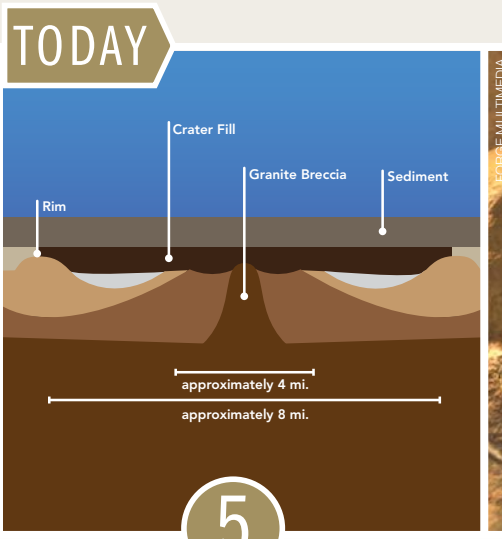
The rock layers settle and the formation takes its final shape. Erosion wears away the crater's sharp peaks.



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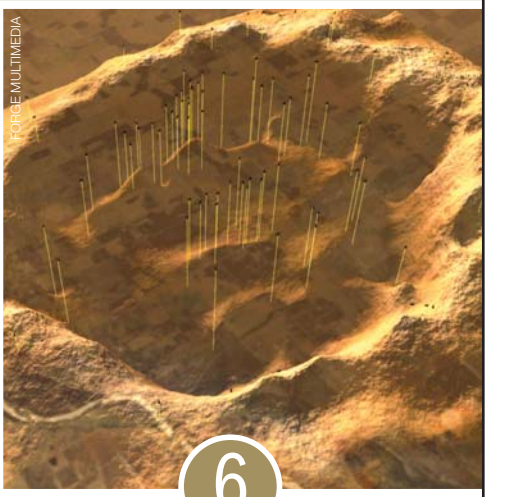
Although more than 9,000 feet of sediment buried the astrobleme over the course of 450 million years, it maintains its general shape below the surface.



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This image shows what the crater would look like today if it were exposed to the surface. The yellow lines represent oil wells and their relative depths.

heal, star wounds inevitably leave a lasting mark on the earth, even if it can't be seen with the naked eye.

The Ames astrobleme remains the largest oil-producing crater in the U.S., but the largest in North America is the gigantic Chicxulub crater beneath the Yucatan Peninsula in Mexico. The crater, speculated to have shaped the Gulf of Mexico ages ago, measures 180 miles in diameter and produces more than two million barrels of oil per day.

A number of factors make impact craters prime candidates for oil exploration. Many of the conditions are created as a result of the initial impact. In the case of Ames, the collision occurred in the Early Ordovician period about 450 million years ago. A meteoroid roughly the size of a football field entered the earth's atmosphere and struck the surface at speeds exceeding 100,000 miles per hour. The resulting impact created a structure known as a complex crater.

While simple craters are merely concave impressions in the ground with an uplifted rim around the perimeter, complex craters contain the additional element of a central uplift. In a cross-section diagram, the uplift is seen as a bump in the middle of the crater. Complex craters also are capable of forming concentric rings within the crater, much like the ripple effect that a bead of water produces when dripped into a standing pool of water. The Ames structure contains both a central uplift and an inner ring, which has a diameter of four miles.

The central uplift, along with the rim, is where the richest oil reserves are found. At the Ames site, the meteorite's impact was so great that it disturbed basement granite lying deep beneath the surface. The granite was shattered and subsequently lithified, forming a type of breccia ideal for trapping oil. The force of the impact actually caused the broken granite to be moved closer to the surface. The impact zone was then covered by seawater, and as organic matter settled into the basin, a potential hydrocarbon source was created.

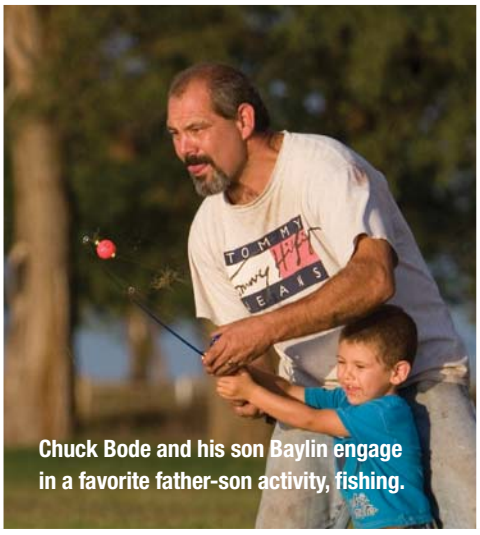
While the impact is classified as Early Ordovician, the granite is much older, dating to the Precambrian era. It is this ancient granite that captivated the geological community: The most impressive rates of production came from the Ames astrobleme's central

Oklahoma City geologist Richard Donofrio studied the Ames astrobleme with Harold Hamm's exploration team.

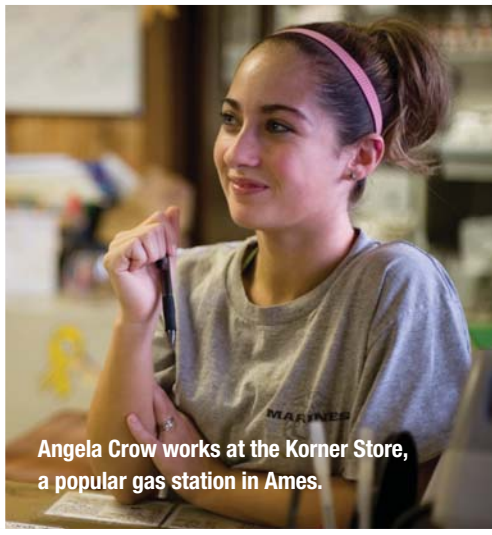
Brent Hajek and his friends work on a '66 Ford Galaxie once driven by NASCAR's Wendell Scott. Hajek operates Hajek Motorsports Museum out of an old school in the town.

John and Christy Sheffield, who have lived in Ames since 1975, take a bike ride every day, weather and schedules permitting.

Bob Scott, pictured with his dog, Duke, owns Ames Glass Company and Cimarron Windmill Company.



Chuck Bode and his son Baylin engage in a favorite father-son activity, fishing.



Angela Crow works at the Korner Store, a popular gas station in Ames.

Jim Gregory mows near the roadside of his property in Ames. The longtime resident says one of his favorite things about living in the community is how supportive its residents are.

{ WHILE THE METEORITE IMPACT CREATED THE PERFECT MECHANISM FOR TRAPPING AND ACCUMULATING OIL, IT IS NOT RESPONSIBLE FOR THE FIELD OF PETROLEUM FOUND THERE. }

CRATER COMFORTS

The Ames Astrobleme Museum makes a big impact on a small town.

Until the discovery of the Ames Hole, local residents were unaware of the significant geological formation two miles beneath their feet.

"We grew up here, and we didn't realize we were living in a crater until 1991," says Bert Mackie, who works closely with Harold Hamm of Continental Resources and is the project manager of the **AMES ASTROBLEME MUSEUM.** "My son and I drove the twenty-five-mile perimeter of the crater, and you can't tell from looking that there's a crater there. There's been enough sediment built up over the last 400 million years that it's impossible to see."

Today, visitors can learn about the crater's history at this one-of-a-kind roadside attraction. The museum, funded by Hamm and Continental Resources, was dedicated at the town's annual Ames Day celebration on August 18, 2007.

The museum consists of a concrete passageway lined with nine illustrated panels depicting the history of the crater from its formation to its eventual discovery and exploration. An on-site video system allows users to view a short educational movie with the press of a button.

"It's a really terrific addition to the town," says Ames city manager Jim Johnson. "We've had visitors and calls from all over." Indeed, the museum shows evidence of visitors from more than thirty U.S. states and at least two foreign countries.

—**JAKE ADAMSON**

The Ames Astrobleme Museum is located at the intersection of Cleo and North Woods Street in Ames. amescrater.com.

uplift, and basement granite is an uncommon source rock.

While the meteorite impact created the perfect mechanism for trapping and accumulating oil, it is not responsible for the field of petroleum found there.

"You still have to obey the laws of hydrocarbon entrapment," says Donofrio. "You have to have a source rock, a reservoir, a seal, and a trap. There's no getting around that. The impact crater just makes it easier."

Although a confirmed impact crater is not a guarantee of a productive oil and gas field, the success rate is high enough for petroleum geologists to take note. Roughly half of the known craters in petroliferous areas of North America are capable of commercial production. Currently, nine out of seventeen craters in North America, plus two anomalies, are commercially viable fields. In every case, the astrobleme's classification was unconfirmed until after the area had been drilled.

Since there are believed to be hundreds of craters on the earth's surface, one might expect petroleum geologists to go to great lengths to find undiscovered craters and exploit their potential reserves.

"Some people went out and said, 'Gosh, we've got to find all these,'" says Hamm.

For the most part, though, geologists are just keeping an eye out for unusual formations.

"The Ames Hole is in the old Sooner Trend field, which was intensely drilled and considered 'developed' by the 1970s," says Jim Puckette, an associate professor of geology at Oklahoma State University in Stillwater. "Because the Ames Hole produced oil and gas from a feature that at shallower depths appears to be a syncline or depression, which are traditionally not the best places to find oil accumulations, it caused geologists to start looking beneath most of the shallow sedimentary sections at features in older rocks."

The Ames Hole's success resurrected an interest in astrobleme exploration that had dropped off in the 1980s. After the Red Wing Creek field and other locations were confirmed as astroblemes in the 1970s, various theories arose about the potential of such features.

In 1983, Donofrio was a consulting geologist for a project in the Siljan crater in Sweden. Scientists there were considering a theory that oil and gas could be produced without organic material if a meteorite impact penetrated through the Earth's crust, reaching the mantle. The Siljan crater was the testing ground for the inorganic hydrocarbon theory. Although the consultants did not recommend the site for commercial drilling, the exploration team's enthusiasm could not be dampened.

"They drilled two wells, and it cost about $60 or $70 million. A lot of people went broke on it," says Donofrio. "There was a lot of discontent and ill feelings toward impact craters in the late 1980s because of what happened at Siljan. Ames was the one that really got the ball rolling again and finally gave a good name to impact craters."

No oil-producing confirmed astroblemes have been discovered in the U.S. since the Ames Hole discovery, but there is no doubt that vast reserves of petroleum may still be found. Various estimates of untapped reserves in North American craters range from 5 to 105 billion barrels. The North American craters that are currently producing have an estimated economic impact of $75 billion a year.

"When I was in high school, it captured my imagination that you could find buried ancient treasure that could create a lot of wealth for whoever found it," says Hamm. "That got my attention, and it still holds it today."