Polarized light shows that the Chebarkul meteorite contains melted and recrystallized material.

ASTRONOMY

The death of the Chebarkul meteor

Scientists reconstruct a battered traveller's final moments.

BY QUIRIN SCHIERMEIER

The city of Chelyabinsk was once a secret Soviet weapons centre, then a poor Siberian backwater. But a few minutes after sunrise on 15 February, the largest meteor blast in more than 100 years lifted the region from obscurity. Since then, scientists have been scrutinizing fragments of the meteorite and studying videos of its final moments to pin down its origin and how it got to Earth.

The picture so far is of a garden-variety envoy from the asteroid belt between Mars and Jupiter, the size of a house and weighing 9,000 tonnes, that had a hard life even before its chance encounter with Earth. "It was a rather fragile body," says Pavel Spurný, a meteor expert at the Ondřejov Observatory near Prague, a member of one of the teams doing the analysis.

His team examined seven videos of the fireball — the largest since the 1908 Tunguska meteorite, which also hit Siberia. The analysis reveals that the meteor first became visible around 92 kilometres above ground. Just over 11 seconds later, at a height of nearly 32 kilometres, it exploded spectacularly under the stress of heating and air drag, damaging thousands of homes and injuring more than 1,000 people in and around Chelyabinsk.

Before its cataclysmic encounter with Earth's atmosphere, the object — dubbed Chebarkul after the small town and lake where some of the largest fragments have been found — seems to have been on an elliptical orbit around the Sun. Stretched between Venus and the centre of the asteroid belt between Mars and Jupiter, the Earth-crossing orbit was just slightly inclined relative to the plane of Earth's orbit around the Sun, the team says in its report to the International Astronomical Union's Central Bureau for Astronomical Telegrams in Cambridge,

Massachusetts. (NASA scientists have ruled out any relation between the Chebarkul meteor and the asteroid 2012 DA14, which skimmed by Earth just hours later.)

A team assigned by the Russian Academy of Sciences to comb the snowy countryside has collected more than 50 fragments measuring 0.5–1 centimetre in diameter. A second group, led by Viktor Grokhovsky of the Urals Federal University in Ekaterinburg, has found another 50 or so pieces, one of which weighs almost 2 kilograms. The samples are being sent to the Russian Academy of Science's Vernadsky Institute of Geochemistry and Analytical Chemistry in Moscow, which has also asked locals for photographs of any fragments they have found.

Inside some of the rocky shards are glassy veins, perhaps created during the impact that broke the object away from its mother asteroid many million years ago. Preliminary geochemical analysis suggests that Chebarkul was a stony meteor with low iron content — a chondrite — made of material that had been partially melted and recrystallized from the dust and gas cloud of the early solar nebula.

A sturdier body might have reached the surface without exploding, but this one probably took a beating after its genesis, having collided with other celestial bodies, says Timothy Spahr, director of the Smithsonian Astrophysical Observatory's Minor Planet Center in Cambridge, Massachusetts. "This could have caused cracks which then resulted in such a powerful blast," says Erik Galimov, director of the Vernadsky Institute.

The search is on for bigger pieces that hold more clues to the meteor's origin and history. Spurný and his colleagues have calculated the final part of the meteor's 254-kilometre flight through the atmosphere and where the largest fragments probably landed (see 'Impact zone').

The fireball zipped through the upper atmosphere at an initial velocity of 17.5 kilometres per second, the team thinks. In the denser air near the ground, the fragments would have slowed to about 180 metres per second, cooled and vanished, says Jiri Borovicka, a co-author of the report.

But calculations based on the fireball's

observed path and on wind profiles suggest that chunks weighing tens of kilograms probably landed close to the village of Travniki, and one weighing around 1 kilogram may have hit northwest of the village of Shchapino, Borovicka says. Thousands of smaller pieces may be hiding in a 25-kilometre-long swathe south of the final point of the trajectory.

The largest single fragment, a piece of rock that could weigh up to half a tonne, may have landed smack in Lake Chebarkul. A 6-metre-wide hole found in the lake's frozen surface the morning after the impact "almost certainly" marks the spot where the whopper came down, says Borovicka.

Russian military divers are busy searching

the shallow lake. But Spahr, who discussed the impact with other scientists at a meeting of the United Nations Committee on the Peaceful Uses of Outer Space in Vienna last month, isn't so sure. "From what we've seen on pictures, the 'crater' just doesn't look right," he says. "It looks more like a hole someone has cut in the lake with an axe." ■

PHYSICS

Metal oxide chips show promise

Materials that flip from insulator to conductor could make energy-efficient transistors.

BY EUGENIE SAMUEL REICH

The switches in most electronic circuits are made of silicon, one of the commonest elements. But their successors might contain materials that, for now, are lab-grown oddities: strongly correlated metal oxides.

The allure of these materials lies in the outer shells of electrons surrounding their metal atoms. The shells are incomplete, leaving the electrons free to participate in coordinated quantum-mechanical behaviour. In some materials, electrons pair up to produce superconductivity, or coordinate their spins to produce magnetism. Other materials can switch from being an insulator to a conductor.

Unlike transitions to superconductivity, which happen as temperatures approach absolute zero, the insulating-to-conducting transition typically happens as temperature increases, and sometimes occurs near room temperature. That has raised hopes that metal oxides could be used instead of silicon to make transistors. A spate of results is now making that look feasible. "People are interested in seeing if oxides can make it to applications," says Manuel Bibes, a physicist at the Joint Physics Unit in Palaiseau, France, which is run by the French National Research Centre and electronics company Thales.

Metal oxide transistors have the potential to consume less power than silicon switches, because the phase transition frees electrons from their localized state near each atom, without moving them through the bulk material. By contrast, silicon switches work by pulling electrons through the material to a channel where they conduct current (see 'Go with the flow').

In the past 5–10 years, researchers have succeeded in growing high-quality thin films of the metal oxides — overcoming one of the major barriers to applications. In July 2012, for example, a group in Japan reported¹ that it had deposited a thin film of vanadium dioxide that underwent a phase transition in response to an

GO WITH THE FLOW

Metal oxide transistors have the potential to consume less power than silicon ones, because switching does not require the atoms to be relocated.

Silicon transistor

A positive charge at the gate draws electrons into a surface channel, allowing current to flow between the source and the drain.

Metal oxide transistor

An applied electric field at the gate causes electrons on metal atoms to become conductive, letting current flow between source and drain.

applied electric field — proof that the material could be used as an electronic switch.

And last month, a group led by Shriram Ramanathan, a materials scientist at Harvard University in Cambridge, Massachusetts, addressed a fabrication challenge by growing a thin film of samarium nickelate on top of a substrate made of silicon and silicon dioxide².

The nickelate was deposited at a relatively low temperature that did not disturb the underlying silicon layers, raising the possibility of manufacturing metal oxides on top of silicon wafers to form three-dimensional chips, says Andrew Millis, a solid-state theorist at Columbia University in New York. Not only would that allow computing power to be packed much more densely, says Millis, but it would also permit metal oxide switches to be built on top of existing circuit architectures.

Other groups are trying to understand the

nature of the phase transition. In January, Ivan Schuller, a solid-state physicist at the University of California, San Diego, and his colleagues showed³ that in vanadium oxide, the transition is in large part caused by micrometre-scale heating by the applied electric field.

Some point to Schuller's work as evidence that metal oxides will never make fast switches, because heating effects are usually quite slow. But Ramanathan says that his own measurements on vanadium oxide demonstrate that the phase transition is quite fast — less than a few nanoseconds — and that it should not hinder applications.

Some physicists are finding further examples of potentially useful materials. Bernhard Keimer at the Max Planck Institute for Solid State Research in Stuttgart, Germany, alternates thin layers of metal oxides to form composites that often turn out to have serendipitous properties. His group layered conducting lanthanum nickelate and insulating lanthanum aluminate and found⁴ that the composite underwent a transition between the two properties.

The highest phase-transition temperature for the composite was 150 kelvin above absolute zero — too low for practical applications. But the group is now trying to replicate the phenomenon in other materials that might have higher transition temperatures.

Sandip Tiwari, an applied physicist at Cornell University in Ithaca, New York, acknowledges that metal oxides are not yet close to competing with silicon. But given recent progress, he feels that researchers need to start trying to implement them in devices. That way, he says, all the properties needed for a good transistor will be developed in tandem. "If you just look at whatever property is your favourite, you won't get them all." ■

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