UNIVERSITÉ DE GENÈVE

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Unlocking the journey of gold through magmatic fluids

By studying sulphur in magmatic fluids at extreme pressures and temperatures, a UNIGE team is revolutionising our understanding of gold transport and ore deposit formation.

Solfatara on Volcano island near the Sicilian coast with elemental sulphur precipitating from volcanic gases originating from magmatic fluids.

High resolution pictures

When one tectonic plate sinks beneath another, it generates magmas rich in volatiles such as water, sulphur and chlorine. As these magmas ascend, they release magmatic fluids, in which sulphur and chlorine bind to metals such as gold and copper, and transport these metals towards the surface of the Earth. As the extreme conditions relevant to natural magmas are very difficult to reproduce in the laboratory, the precise role of the different forms of sulphur in metal transport remains highly debated. However, an innovative approach by a team from the University of Geneva (UNIGE) has demonstrated that sulphur, in its bisulphide (HS^-) form, is crucial for the transport of gold in magmatic fluids. These findings are published in *Nature Geoscience*.

When two tectonic plates collide, the subducting plate plunges into the Earth's mantle, heats up and releases large amounts of water. This water lowers the melting temperature of the mantle, which melts under high pressure and temperatures exceeding a thousand degrees Celsius to form magmas. As the liquid magma is less dense than the rest of the mantle, it migrates towards the Earth's surface.

"Due to the drop in pressure, magmas rising towards the Earth's surface saturate a water-rich fluid, which is then released as magmatic fluid bubbles, leaving a silicate melt behind" explains Stefan Farsang, a postdoctoral fellow at the Department of Earth Sciences at UNIGE's Faculty of Science and first author of the study. Magmatic fluids are therefore composed partly of water, but also of dissolved volatile elements such as sulphur and chlorine. These two elements are crucial because they extract gold, copper and other metals from the silicate melt into the magmatic fluid, thus facilitating their migration towards the surface.

Several forms of sulphur

Sulphur can easily be reduced or oxidised, i.e. gain or lose electrons, a process known as redox. The redox state of sulphur is important because it affects its ability to bind to other elements, such as metals. However, one debate has divided the scientific community for more than a decade: what is the redox state of the sulphur present in the magmatic fluid that mobilizes and transports metals?

Zoltán Zajacz, associate professor in the Department of Earth Sciences at UNIGE's Faculty of Science and coauthor of the study, explains: "A seminal paper in 2011 suggested that S3- sulphur radicals play this role. However, the experimental and analytical methods had several limitations, particularly when it came to reproducing relevant magmatic pressure-temperature and redox conditions, which we have now overcome."

Methodological revolution

The UNIGE team placed a quartz cylinder and a liquid with a composition similar to that of a magmatic fluid in a sealed gold capsule. The capsule was then put into a pressure vessel, which was then brought to pressure and temperature conditions characteristic of magmas emplaced in the Earth's upper crust. "Above all, our setup facilitates flexible control of the redox conditions in the system, which wasn't possible before," adds Stefan Farsang.

During the experiments, the quartz cylinder is fractured, allowing the synthetic magmatic fluid to enter. The quartz then traps microscopic-sized droplets of fluid like those found in nature, and the form of sulphur in these can be analysed at high temperature and pressure by using lasers with an analytical technique known as Raman spectroscopy. While previous spectroscopic experiments were typically run up to 700 °C, the UNIGE team succeeded in raising the temperature to 875 °C characteristic of natural magmas.

Bisulphide as a transporter

The study shows that bisulphide (HS-), hydrogen sulfide (H_2S) and sulphur-dioxide (SO_2) are the major sulphur species present in the experimental fluids at magmatic temperatures. The role of bisulphide in metal transport was already well documented in lower-temperature so-called hydrothermal fluids that originate from the higher-temperature magmatic fluids. However, bisulfide was thought to have very limited stability at magmatic temperatures. Thanks to their cutting-edge methodology, the UNIGE team was able to show that in magmatic fluids too, bisulphide is responsible for transporting most of the gold.

"By carefully choosing our laser wavelengths, we also showed that in previous studies, the amount of sulphur radicals in geologic fluids was severely overestimated and that the results of the 2011 study were in fact based on a measurement artefact, putting an end to this debate," says Stefan Farsang. The conditions leading to the formation of important precious metal ore deposits have now been clarified. Since much of the world's copper and gold production comes from deposits formed by magma-derived fluids, this study may contribute to their exploration by opening up important perspectives for understanding their formation.

contact

Stefan Farsang
Postdoctoral fellow
Department of Earth sciences
Faculty of Science
UNIGE
+41 22 379 66 76
Stefan.Farsang@unige.ch

Zoltán Zajacz
Associate professor
Department of Earth sciences
Faculty of Science
UNIGE
+41 22 379 66 22
Zoltan.Zajacz@unige.ch

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UNIVERSITÉ DE GENÈVE
Communication Department
24 rue du Général-Dufour
CH-1211 Geneva 4

Tel. +41 22 379 77 17

media@unige.ch
www.unige.ch