CURIOUS ABOUT SCIENCE

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The fingerprint of the monsoon –
how researchers reconstruct the climate history of Earth

"Tell me the past and I will know the future." The Chinese philosopher Confucius knew this over 2,500 years ago. Although his teachings were about the ideal, morally faultless human being, his wisdom can also be applied to other issues such as climatic variability in both the past and in the future. "Only when we are aware of and understand the climate changes of the past can we make well-founded predictions about the future", says Gerd Gleixner, Research Group Leader at the Max Planck Institute for Biogeochemistry in Jena.

Researchers like Gleixner started investigating climate history quite some time ago. Delving into the past shows that the Earth's climate has not remained stable at all but rather has changed continuously since its formation 4.6 billion years ago. There were periods with extremely cold conditions. There were also times when the Earth's climate was much hotter than it is today and the polar ice caps were completely melted. Such a greenhouse climate may soon be upon us again. This is mainly due to the burning of oil, coal, and gas that started during the industrial revolution and the associated increase in carbon dioxide (CO_2) in the atmosphere. As a result, the surface temperatures of the Earth's land areas and oceans have increased by 0.87 °C between 1880 and 2012 (see Geomax 22).

One of the hotspots of human-induced climate change is Central Asia. Researchers predict that if the current warming trend continues, two-thirds of the glaciers on the Tibetan Plateau – also known as the Earth's "third pole" – will have disappeared by as soon as 2050. In order to make such predictions, it is important to understand the natural climate variations of the past. In order to obtain a detailed picture of the climatic changes that occurred during the Holocene (i.e. the last 11,700 years), **palaeoclimatologists** journey into the region's past. "This period is particularly exciting because it was crucial for the development of human societies", says Gleixner. However, there is still no holistic picture of the climatic development in Asia Minor during the Holocene. This is mainly because of the complex interplay of competing influencing factors that regulate the regional climate.

BETWEEN FLOOD AND DROUGHT

In general, the climate system of Central Asia is influenced by the interaction of the westerly winds, the Indian Summer Monsoon (ISM), and the East Asian Summer Monsoon (EASM) **(Fig. A)**. The **monsoons** are characterized by the strong, seasonally changing winds, which Arab seafarers used for their extensive journeys over a

FIG. A: WHICHEVER WAY THE WIND BLOWS

Different air masses influence the climate of Central Asia: The Indian and East Asian summer monsoons bring warmth and plenty of moisture, while the winter monsoon and westerly winds bring cold and dryness.

thousand years ago. The monsoon season is also marked by heavy rainfall, some of which can reach torrential proportions. The large-scale monsoon system – which influences the climate not only in Asia, but also in northern Australia and East Africa – is driven by differences in air pressure over the sea and the continents.

The importance of these atmospheric systems is enormous: Over 60% of the world's population depends on the Asian monsoon system alone. If it rains too much at once, devastating floods and landslides occur. On the other hand, if the monsoon rains do not come or come too late or are too fleeting, there will be a lack of rainfall in many regions. Palaeoclimatic records show that the Asian monsoon has fluctuated greatly in the past – over both short and long periods of time. Over the past millennia, drought has led to the demise of cultures such as the Tang, Yuan, and Ming dynasties of China.

Changes in the Earth's orbit and solar activity are the two most important external factors influencing the monsoon and thus the global climate. Changes in the Earth's orbit occur with a periodicity of about 100,000 years, 41,000 years, and 23,000 years, thereby leading to periods of high or low solar radiation in the northern hemisphere. The middle latitude position of the intertropical convergence zone (ITCZ) shifts according to the levels of irradiation, which also alters the levels of evaporation and convection over the Indian Ocean. The sun's activity rises and falls in cycles ranging from 11 to 2,300 years. High solar activity increases equatorial convection; this, in turn, results in more precipitation in the monsoon regions. Low solar activity has the opposite effect.

On shorter time scales, the Asian monsoon is influenced by other climate phenomena such as the El Niño Southern Oscillation (ENSO). El Niño conditions (warm surface water in the Eastern and Central Pacific with increased atmospheric convection) usually lead to droughts in the Asian monsoon areas. On the other hand, La Niña – the opposite of El Niño – intensifies the monsoon and causes floods and storms. Together with external factors such as solar radiation, these climate variables lead to the variability of the Asian monsoon system on different time scales and ultimately to a complex pattern of climatic events in the tropics and subtropics. Differentiating between these factors on varying time scales is one of the challenges of monsoon research.

SEARCHING FOR TRACES IN THE LAKE

Kasun Gayantha and Natalie Schröter are members of Gleixner's research group and study the monsoon fluctuations on the Tibetan Plateau and in the mountain ranges of Central Asia. For their investigations, the Jena researchers chose Lake Chatyrköl in Kyrgyzstan, which lies at a high altitude (approx. 3,500 m above sea level) in the Tian Shan Mountains. The area regulates the climate and water balance of northern Central Asia and promises not only valuable ecological but also cultural information. This is because Kyrgyzstan lies on the ancient Silk Road and was a "cultural bridge" between Asia and Europe. "During the surface water survey, we stayed in a caravan with a Kyrgyz family. There was no running water or electricity, and it was very isolated. Because of the low oxygen content at this altitude, you have to be careful. The solar radiation is also extremely high", says Schröter. The palaeoclimatologists use samples from **lake sediments** in order to trace past changes in monsoon precipitation levels and their environmental impact. Obtaining the samples from the lake sediments requires immense effort. "You need several truckloads of equipment to drill a single borehole. It all has to be transported to an altitude of over 3,500 m. Fortunately, there is now a road leading to Lake Chatyrköl. A large team must then work more than four weeks to drill for samples", says Gleixner.

A GLIMPSE INTO PAST CLIMATES

Once the valuable samples have been taken from the drill core, the researchers analyse isotopes in biomarkers in order to reconstruct the climatic conditions in the past. **Biomarkers** are organic compounds preserved in geological material (e.g. lake sediment) and can be traced back to a living organism or a process such as photosynthesis. Isotopes are atoms of a chemical element that have different masses. Hydrogen exists mainly as the light hydrogen isotope ^{1}H (one proton in the nucleus) and to a very small extent as the heavy hydrogen isotope ^{2}H (one proton and one neutron in the nucleus). When **analysing isotopes**, researchers use the varying masses to determine the proportion of the various isotopes of a particular element in a sample. The ratios of light to heavy hydrogen in the organic compounds measured in the sample provide information about the climate and environment in the past. "It took almost 20 years for this method to become established in palaeoclimatology. It had to be tested in different systems so that we could be sure that the analysis of hydrogen isotopes works in our field of research", explains Gleixner.

The researchers use the different behaviour of the two hydrogen isotopes to reconstruct the climate. When water evaporates, the light hydrogen isotopes pass more quickly into the gas phase, thereby shifting the isotopic signature. This process is referred to as isotope fractionation and is strongly dependent on the ambient temperature. During warm periods with higher evaporation, the heavy hydrogen isotope accumulates in the groundwater and in water bodies; during colder periods with lower evaporation, the proportion of the lighter hydrogen isotope is higher.

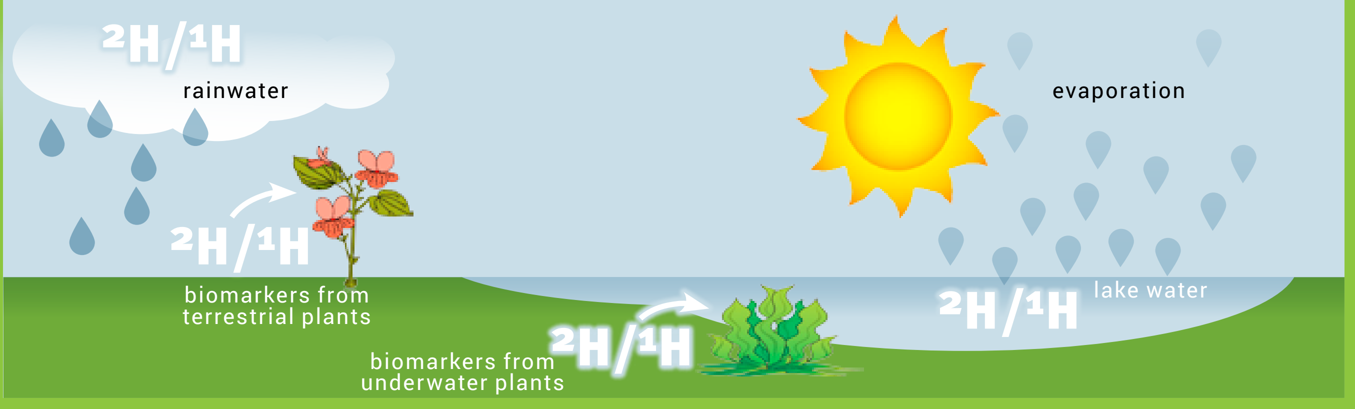
Plants use the water from their surroundings: They build up biomass through photosynthesis during which hydrogen enters their stems, leaves, and flowers as a component of organic molecules. The "isotopic fingerprint" of water – the ratio of light to heavy water – is recorded in the organic material. When the plants die, their remains are deposited in the form of fossils in the sediments of lakes, rivers, or seas. When climate researchers examine sediment samples from Central Asia, they can visualize the isotopic fingerprint of the plants, which was formed thousands of years ago, and thus reveal past precipitation and evaporation scenarios.

For example, researchers use hydrogen isotope analysis of unbranched n-alkanes from leaf waxes as a palaeohydrological parameter (δD) in order to understand the behaviour of the monsoon system in the past (Fig. B). The isotope fractionation in rainwater depends mainly on its quantity or intensity as well as the source of moisture in tropical monsoon areas. When terrestrial plants take up water from the soil and form leaf waxes, the original content of hydrogen isotopes in the local rainwater can be traced by analysing the long-chain alkanes. In contrast, underwater plants and floating plants in the lake use the surrounding water as their primary water source. The short-chain alkanes found in the leaf waxes of these plants therefore allow the reconstruction of the isotope content of the lake water. The hydrogen isotope ratios of aquatic and terrestrial alkanes thus provide information on the ratio of water loss through evapotranspiration and water gain through precipitation (evaporation-to-inflow index). Evapotranspiration is the sum of direct water evaporation and of transpiration from the surface area of plants. The index also shows whether water intake or loss changed the water balance.

PEOPLE ON THE MOVE

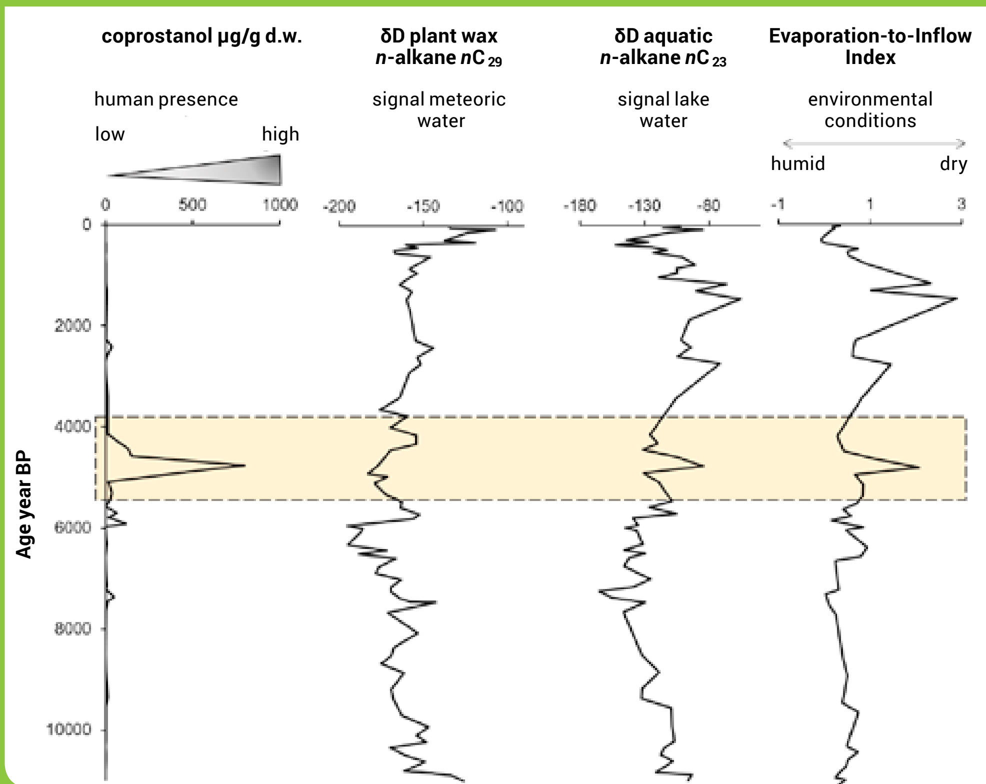
The research group also wants to find out how people adapted to changing environmental conditions in the past. To do this, they combine isotope analysis with the faecal biomarker **coprostanol**,

FIG. B: WHAT BIOMARKERS REVEAL



The isotopic fingerprint of rainwater is stored in terrestrial plants and the isotopic ratio of the lake water is stored in underwater plants. The difference between the two values is used to calculate an index, which provides information about the degree of evaporation. From this, a rather dry or humid climate is deduced.

FIG. C: ENLIGHTENING COMBINATION



The coprostanol concentration of 8000 µg per gram of dry matter indicates the presence of humans at Lake Chatyrköl between 6,000 and 4,000 years BP (before 1950). The evaporation-to-inflow index indicates dry environmental conditions. The index is calculated from the composition of hydrogen isotopes (δD) in terrestrial and aquatic n-alkanes. The greater the value of δD, the higher the content of the heavy isotope. During dry periods, heavier hydrogen accumulates in lake water, and the proportion in rainwater is lower.

which is produced during the microbial degradation of cholesterol in the intestinal tract of humans and animals. Higher concentrations of coprostanol in the sediment samples reveal the presence of humans. The earliest indication of human presence at Lake Chatyrköl is shown by a peak in coprostanol concentrations from about 5,900 years BP (before 1950) and especially at about 4,800 years BP (Fig. C). At the same time, the values for the E/I index are also rising, thus indicating dry periods. "We assume that people migrated to Lake Chatyrköl during this period. It was probably too dry in the lowlands. So they moved to higher, cooler regions", explains Gleixner. The difficult environmental conditions in the lowlands, the better accessibility to the higher regions, and the need for new grazing areas because of limited resources may have led people to settle in the area around Lake Chatyrköl during the dry season.

A GLIMPSE INTO THE FUTURE

There is still a lot to do before a complete climatic and environmental dataset from Central Asia can be compiled. In order to reveal the region's climatic history, researchers from all over the world are studying many different lakes in Central Asia. "The more sampling sites and records we have over a wide geological time span, the better we will be able to understand the behaviour of the monsoon system", says Gleixner. A deep drilling has therefore been planned in order to extract a particularly long sediment core from Lake Nam Co on the Tibetan Plateau. Such a sediment core would reveal environmental variability over long time spans. Deep drilling is also planned in areas near the equator (e.g. Sri Lanka) in order to better understand the essential components of the Asian monsoon system. Gleixner predicts that, "At some point, our record of tropical and subtropical monsoon variability throughout geological history will help us develop climate models that can better predict future climate trends in the region". This will help countries in the monsoon areas to develop timely ways of dealing with climate change.

Keywords
biomarker, coprostanol, isotope analysis, climate variability, monsoon, palaeoclimatology, lake sediments

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