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Three High-Altitude Peoples, Three Adaptations to Thin Air

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Prehistoric and contemporary human populations living at altitudes of at least 8,000 feet (2,500 meters) above sea level may provide unique insights into human evolution, reports an interdisciplinary group of scientists.

Indigenous highlanders living in the Andean Altiplano in South America, in the Tibetan Plateau in Asia, and at the highest elevations of the Ethiopian Highlands in east Africa have evolved three distinctly different biological adaptations for surviving in the oxygen-thin air found at high altitude.

"To have examples of three geographically dispersed populations adapting in different ways to the same stress is very unusual," said Cynthia Beall, a physical anthropologist at Case Western Reserve University in Cleveland, Ohio. "From an evolutionary standpoint the question becomes, Why do these differences exist? We need to figure out when, how, and why that happened."

To begin to answer some of these questions, a multidisciplinary group of scientists, including Beall, met earlier this month at the annual meeting of the American Association for the Advancement of Science in Seattle, Washington.

"High-altitude populations offer a unique natural lab that allows us to follow [many] lines of evidence—archaeological, biological, climatological—to answer intriguing questions about social, cultural, and biological adaptations," said Mark Aldenderfer, an archaeologist at the University of California, Santa Barbara, who organized the AAAS symposium with Beall.

(Aldenderfer and Beall are both past recipients of research grants from the National Geographic Society Committee for Research and Exploration.)

Adapting to High Altitudes

The Andean and Tibetan plateaus rise some 13,000 feet (4 kilometers) above sea level. As prehistoric hunter-gatherers moved into these environments, they encountered desolate landscapes, sparse vegetation, little water, and a cold, arid climate.

In addition, early settlers to the high plateaus likely suffered acute hypoxia, a condition created by a diminished supply of oxygen to body tissues. At high altitudes the air is much thinner than at sea level. As a result, a person inhales fewer oxygen molecules with each breath.

Symptoms of hypoxia, sometimes known as mountain sickness, include headaches, vomiting, sleeplessness, impaired thinking, and an inability to sustain long periods of physical activity. At elevations above 25,000 feet (7,600 meters), hypoxia can kill.

The Andeans adapted to the thin air by developing an ability to carry more oxygen in each red blood cell. That is: They breathe at the same rate as people who live at sea level, but the Andeans have the ability to deliver oxygen throughout their bodies more effectively than people at sea level do.

"Andeans counter having less oxygen in every breath by having higher hemoglobin concentrations in their

blood," Beall said. Hemoglobin is the protein in red blood cells that ferries oxygen through the blood system. Having more hemoglobin to carry oxygen through the blood system than people at sea level counterbalances the effects of hypoxia.

Tibetans compensate for low oxygen content much differently. They increase their oxygen intake by taking more breaths per minute than people who live at sea level.

"Andeans go the hematological route, Tibetans the respiratory route," Beall said.

In addition, Tibetans may have a second biological adaptation, which expands their blood vessels, allowing them to deliver oxygen throughout their bodies more effectively than sea-level people do.

Tibetans' lungs synthesize larger amounts of a gas called nitric oxide from the air they breathe. "One effect of nitric oxide is to increase the diameter of blood vessels, which suggests that Tibetans may offset low oxygen content in their blood with increased blood flow," Beall said.

A pilot study Beall conducted of Ethiopian highlanders living at 3,530 meters (11,580 feet) suggests that—unlike the Tibetans— they don't breathe more rapidly than people at sea level and aren't able to more effectively synthesize nitric oxide. Nor do the Ethiopians have higher hemoglobin counts than sea-level people, as the Andeans do.

Yet despite living at elevations wih low oxygen content, "the Ethiopian highlanders were hardly hypoxic at all," Beall said. "I was genuinely surprised."

So what adaptation have the Ethiopian highlanders' bodies evolved to survive at high altitude? "Right now we have no clue how they do it," Beall said.

Tracking Prehistoric Migrations

Knowing how long the populations have been living at the top of the world is crucial to answering the evolutionary question of whether these adaptations are the result of differences in the founding populations, random genetic mutations, or the passage of time.

Archaeologists, paleontologists, and climatologists are pooling their knowledge to pinpoint when some of these early migrations to the high plateaus occurred.

Aldenderfer, the University of California, Santa Barbara, archaeologist, says cultural adaptations would have to occur first.

"The ability to survive in such harsh environments required control of fire, an expanded tool kit that included bone needles to make complicated clothing that protected the body in a significant way, and the cultural flexibility to change subsistence practices," he said.

Climatologists' changing understanding of the nature of the last ice age is contributing to archaeological efforts.

Ice-core and other evidence show that, rather than being a monolithic period lasting 100,000 years with frigid temperatures and glacial landscapes, the Ice Age included long periods of relatively mild weather.

"Through most of the 20th century it was thought that the Tibetan Plateau was covered by a monstrous ice sheet during the last glacial maximum, about 21,000 years ago," Aldenderfer said. "People couldn't live on an ice sheet. So archaeologists wouldn't even bother to look for sites from that time period."

Knowing the Tibetan Plateau more closely resembled Arctic tundra has lead to the discovery of new sites. Archaeological evidence suggests hunter-gatherers occupied the Tibetan plateau some 25,000 to 20,000 years ago. People began moving into the Andean Altiplano around 11,500 to 11,000 years ago.

What motivated prehistoric people to move into the harsh and challenging conditions presented by high altitude?

"The highlands offered an attractive option with a landscape that was open and pristine," Aldenderfer said. "People probably started out moving up and down for short terms, and then gradually settled at the higher elevations."

Changing environmental conditions also created "new opportunities and new constraints," he said.

In South America, for example, the maritime environment began transforming as temperatures warmed, glaciers retreated, and sea levels rose. Large mammals such as mammoths and mastodons gradually went extinct, as did other herbivores. Warmer temperatures allowed plants and animals to move to higher elevations, creating resource-rich patches of habitat in highland areas. Familiar coastal resources also changed as fish and shellfish habitats shifted.

Similar processes likely occurred in Tibet. Prehistoric people occupied the landscape during the interglacial process, when conditions were relatively benign and hunting was plentiful, Aldenderfer said.

"Suddenly it gets really cold. Biomass declined precipitously. It becomes very arid because of wind-flow patterns. The landscape becomes one of very patchy vegetation, rocky. And the huge herds of gazelle, antelope, and sheep wax and wane," Aldenderfer said. "What happens? Do the people adapt and tough it out? Did they abandon the highlands? Or do these early populations more or less go extinct? There's no evidence yet. But finding biological differences suggests they toughed it out and adapted."
