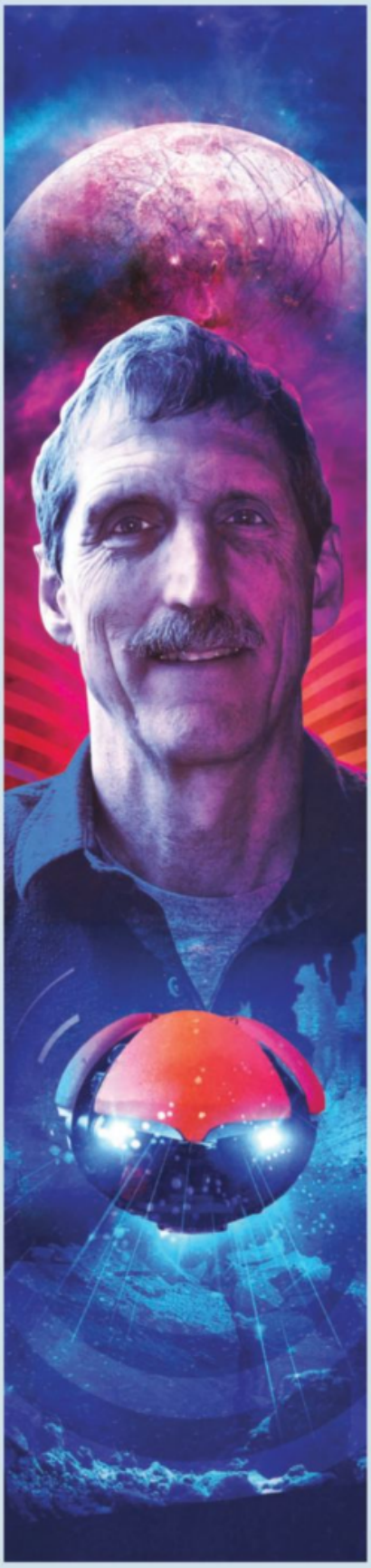

The caveman in space

Bill Stone is a cave explorer who has discovered new things about the Earth. Now he will try to do the same with robots on another planet

AFTER nearly two weeks of pushing deeper into a vast cave network in the Mexican state of Oaxaca, Bill Stone faced a grim errand. He strapped on a special scuba rig called the Mk4 and disappeared into the frigid, stalactite-pierced water of a flooded tunnel. Three hours later he returned with a drowned colleague. It took his team five days to haul the body out. Other expedition members, trapped by rising water, took several days longer to reach sunlight. The 1994 National Geographic Society expedition into the Sistema Huautla, the deepest cave network in the Western hemisphere, which Dr Stone was leading, reveals much about the American explorer and engineer.

Dr Stone's thirst is for the adventure of discovery and it drives him hard. Mapping the few unexplored areas left in the world is dangerous, but risks can be managed provided people know their capabilities. Of the expedition's surviving 44 cavers, only Dr Stone and a handful of others turned around to go back into the cave system for another 18 days to explore 3.3km (2 miles) of virgin territory. Unless new knowledge is acquired, Dr Stone said later, "you've accomplished nothing."

Now 61 and still pushing himself on, Dr Stone nevertheless appreciates the limits of human exploration. Over the years 23 of his friends lost their lives on expeditions and he has personally recovered seven bodies (three as a rescuer and four as an expedition member). These tragedies have heightened his determination to develop new technology to extend humanity's reach further into the unknown.

The Mk4 which Dr Stone wore to recover his colleague was one of his inventions. It is a "rebreather", which recycles exhaled air using lithium hydroxide to absorb toxic carbon dioxide. This leaves behind unmetabolised oxygen, which can be breathed again. The drowned diver was also using a Mk4 and Dr Stone brought it back with the body to help determine what had gone wrong. The device's "black box" revealed no anomalies and doctors concluded that, being a diabetic, the diver had suffered a hypoglycaemic blackout. Rebreathers are now widely used by cavers and deepwater divers because they can stay underwater a lot longer than they can using conventional scuba gear.

As the places Dr Stone tries to reach become more difficult and dangerous his equipment is becoming ever more elaborate. A series of robotic exploration vehicles are now emerging from his company, Stone Aerospace, which is based near Austin, Texas. It is with these machines that Dr Stone plans to venture where he has always longed to go: to search for life on another planet.

De profundis ad astra

With funding from NASA, America's space agency, Stone Aerospace is developing a team of robots to hunt for microbial life on one of Jupiter's moons, Europa. Putting robots on Europa, some 628m kilometres from Earth, would be relatively straightforward—rovers have been placed successfully on Earth's Moon and on Mars. And NASA's *Galileo* spacecraft has laid the groundwork with reconnaissance flights. If Europa harbours life, it is most likely to be in a dark ocean sealed by an ice cap kilometres thick.

To investigate how to get below that ice cap, a team led by Dr Stone is due to arrive on Alaska's Matanuska glacier in June to begin testing an ice-penetrating robot. This would disgorge swimming robots, which Stone Aerospace is developing, into Europa's ocean. One model, DepthX, has been built with $5m from NASA and help from groups including Carnegie Mellon University, the University of Texas, Austin, and Southwest Research Institute, a Texas-based R&D organisation.

For the swimming robots to operate under the ice so far from Earth they have to be autonomous. DepthX, accordingly, generates its own commands with three dozen computers that crunch data from various instruments, including a microscope, cameras, accelerometers, velocity loggers and multiple sonar systems.

DepthX's navigation system includes a ring-laser gyroscope, which collects inertial data so the vehicle can swim back to its starting-point. In the shape of an ellipsoid about the size of three refrigerators, it can swim in any direction and is unlikely to snag on obstacles. To determine where life might lurk, it can detect changes in water temperature and chemistry, and look at variations in rock colour and texture for clues. If, for example, DepthX detects an increase in hydrogen sulphide (which can be produced by the bacterial breakdown of organic matter) of more than 700 parts per million, it would decide to investigate the area further.

Stone Aerospace runs more like a storyline from "Mission: Impossible" than an ordinary company

Depthx has already autonomously collected rock samples from the world's deepest sinkhole, El Zacatón, in Tamaulipas state, Mexico. These yielded four new phyla of bacteria at a time when fewer than 100 were known to science, according to biologists who studied the material at the University of Colorado, Boulder and the Colorado School of Mines. Stone Aerospace is now developing a smaller and more capable swimming robot which it will also sell to other explorers.

As might be expected, Stone Aerospace runs more like a storyline from "Mission: Impossible" than an ordinary company. For each project, Dr Stone taps what he calls the relevant "virtuosos" from 50 or so regular collaborators. Engineers for the most part, these people work "where they think best" (which is usually where they chose to live), uploading designs to the company's machine shop before flying to Texas to assemble and test the kit.

It is a far cry from the sprawl of NASA, which Dr Stone can be critical of, although it paid for much of his work. He thinks the agency's bureaucracy pushes up the cost of missions and keeps too many astronauts grounded with overly cautious safety concerns. A former NASA official jokes that part of his job was to keep Dr Stone "away from the rest of the bureaucracy to the maximum possible extent".

This is hardly surprising. NASA rejected Dr Stone's application to be an astronaut. Armed with a pilot's licence and an engineering PhD, he got to the semi-final of the selection process in 1989, but says he failed to make the cut for being "too independent for teamwork".

As independent, perhaps, as his robots will need to be in their hunt for organisms in Europa's lightless ocean. The idea that such life may exist on other planets has become more plausible with scientific advances. Oceanographers have discovered deep-sea hydrothermal vents that support organisms, such as chemosynthetic bacteria, with heat and chemicals rather than sunlight-fuelled photosynthesis. The *Galileo* mission and the Hubble telescope have led scientists to believe that Jupiter's fluctuating gravitational pull on elliptically orbiting Europa generates enough frictional heat in its core for hydrothermal vents to bring warmth and chemical energy up into its ocean.

Late next year a new NASA-funded Stone Aerospace robot, named ARTEMIS, will swim under Antarctica's Ross Ice Shelf to scan for life with a deep-ultraviolet laser that induces fluorescence in microbes. It will also map the shelf's underside to help calibrate the airborne ice-penetrating radar that NASA's proposed Europa Clipper mission would use to measure ice thickness as it flies close to the surface. The ice may be tens of kilometres thick in some areas, so identifying the thinnest spots for the penetrator to get through is important. Even then, building the robot will be the most technologically daunting aspect, says Bart Hogan, Stone Aerospace's chief engineer.

Using heat from a radioisotope thermoelectric generator (RTG) to warm its shell, the penetrator could melt its way through. RTGs are not much larger than a microwave oven and are already used to generate power on space missions. But for testing on Earth, a different solution is needed. Nuclear equipment is banned in Antarctica, and elsewhere tinkering with RTGs is expensive and bureaucratically cumbersome. Dr Stone imagined an alternative solution in Mexico in 2008.

Laser focus

After slipping into "one of these little Zen states" while watching a fibre-optic data link spool out as Depthx sank into a sinkhole, Dr Stone wondered if the link could carry enough photons, generated by a laser on the ground above, to heat a penetrator to an ice-melting temperature. Eventually, NASA decided to fund the development of a nearly 2-metre-long cylindrical laser-powered penetrator that will be tested on the Matanuska glacier.

Stone Aerospace named the penetrator VALKYRIE. This is not in reference to the Norse deity but rather because it needed "a frickin' cool acronym", Dr Stone says. And, contrived as it is, Very Deep Autonomous Laser-Powered Kilowatt-Class Yo-Yoing Robotic Ice Explorer fitted the bill. Dr Stone describes it as a "heated shell that carries all the junk that's really gonna do business" once it's ejected into Europa's ocean. VALKYRIE will, however, use a fluorescence spectrometer to scan the ice column for proteins during the Alaska testing. The name has now come to refer to Stone Aerospace's entire Europa effort.

Dr Stone believes that humanity could be just years from discovering extraterrestrial life. Even if life or its vestiges are found on Europa then it would still be necessary to prove that the organisms had not hitched a ride into space from Earth, either on a spacecraft or from rocks ejected into space by an asteroid impact. So the robots will compare samples against a library of Earth's micro-organisms.

The discovery of Europan life would, Dr Stone reckons, be "a pretty good contender" for one of the most momentous events in human history. That might satisfy most explorers, but not Dr Stone. He has founded the Shackleton Energy Company (SEC) to process water on the Earth's Moon into oxygen and hydrogen for rocket fuel. It can cost around $16,000 per kilo to send supplies like fuel into low Earth orbit. Transporting fuel to the Moon would cost at least five times as much, says Jeffrey Hoffman, a space-flight expert at the Massachusetts Institute of Technology who is familiar with SEC. The ability to produce fuel in space, he thinks, would slash the cost of missions from placing geostationary satellites to interplanetary travel.

To fill its first customer's fuel tank, SEC needs a decade of development and about $18 billion, says Dale Tietz, the company's chief executive. If the firm can interest enough wealthy investors that is attainable, reckons Mr Tietz, a former senior official in the Pentagon's ultimately abandoned Strategic Defence Initiative for space-based missile defences.

To man the refuelling base on the Moon, SEC will not recruit the sort of people NASA might hire. Instead it intends to look for men and women who are up for an adventure. They would not be "astronauts"—a term Mr Tietz avoids—but "industrial operators" with the rugged-individualist spirit of wildcatters. To return home from the Moon, the first work crew will need to produce the fuel required for their journey, says Dr Stone. That is a big risk, but it is one Dr Stone is prepared to take, as he intends to lead those workers himself. ■