A radon-resistant microbial community

Introduction
Over the past few decades, microbes have been discovered in a positively bewildering array of extreme environments. Bacterial and archaeal extremophiles exist, and often thrive, in conditions that would quickly kill eukaryotes, such as extremes of temperature, pH, pressure, salinity and radiation.

Deinococcus radiodurans is the champion with respect to the latter, being able to withstand doses of ionising radiation that would kill us feeble humans many times over; it can survive acute doses of gamma-radiation as high as 1,700,000 rads, whereas 500-1000 rad is lethal to humans\(^1,2\). Other examples of radiation-resistant microbes are known (e.g. other Deinococcus sp., Kineococcus radiotolerans, some Rubrobacter sp.), but none, including D. radiodurans, has been associated with high levels of radioactive radon. Recently, we were the first research group to describe a diverse microbial community flourishing in a radon-rich, thermal environment, the Paralana hot spring\(^3,4\).

Paralana and Astrobiology
Paralana is located near Arkaroola, in the Northern Flinders Ranges of South Australia. The hot spring system consists of two small, interconnected pools that contain obvious microbial mats and biofilms (Figure 1).

Water which issues from the sandy bottom of the smaller pool is at 60-63°C (pH 7); this drops off to 48°C in the larger pool. The water is believed to be heated by both geothermal processes and radioactive decay. Gas which bubbles into the pool contains radon (from the radioactive decay of radium), 88% nitrogen, 12% carbon dioxide, and trace helium and hydrogen. The radon levels are higher in the gas than in the spring water: 29000 Bq/L versus 2000-5800 Bq/L, respectively\(^5,6\). The radon level in the gas is approximately two million times the average background reading in outdoor air\(^7\). The alpha radiation emitted by radon is known to cause DNA damage in both prokaryotic and human cells\(^8,9\). In humans, it is recommended that exposure be kept below approximately 0.15 Bq/L to avoid an increased risk of lung cancer\(^10\).

Paralana is of particular interest for Astrobiology because the conditions – a hydrothermal system, ionising and...
ultraviolet (uv) radiation – are believed to be analogous to those present on the early Earth. It therefore represents an excellent laboratory for studying the origin and evolution of life. For example, studies conducted there may shed light on the currently popular theory that life evolved in a hydrothermal environment.

Where are the radiation-resistant microbes?

Molecular-based 16S rRNA studies using both bacterial and archaeal-specific primers indicated that Paralana supports a diverse microbial community. In general, the microorganisms identified (representing either previously cultured or uncultured microbes) are those expected in a hot spring. Examples include cyanobacteria (e.g. Oscillatoriales, Stigonematales), proteobacteria (e.g. Hydrogenophilus thermoluteolus), green sulphur and green non-sulphur bacteria, and thermophilic crenarchaeota. Figure 2 shows a filamentous cyanobacterial sample from Paralana. There is currently no data on the resistance of these microbes to radon.

Whilst these results are not particularly remarkable for a thermal pool, the presence of radon means that Paralana is definitely not your standard, run-of-the-mill hot spring. We were therefore somewhat surprised that no previously described radiation-resistant microbes were identified (e.g. the thermophiles Deinococcus geothermalis and D. murrayi). However, there were some tantalising hints – identification of a 16S rRNA sequence 93% homologous to a sequence originally identified in the anaerobic drain waters of uranium waste piles; the presence of archaeal halophile sequences, interesting because it has been demonstrated that a halophile, Halobacterium salinarum, is resistant to ionising radiation; and the identification of a gene sequence coding for a protein with homology to a hypothetical D. radiodurans protein [M. Gillings, personal communication]. Nonetheless, there was no conclusive evidence of the presence of radiation-resistant microbes in Paralana. To investigate further, we designed Deinococcus species-specific 16S rRNA primers with which to analyse the DNA extracted from the hot spring samples. No Deinococcus sequences were identified. Primers specific for other species resistant to ionising radiation will be tested in the future.

Of course, it is possible that no such ‘classical’ radiation-resistant microbes are present in Paralana. An intriguing possibility is that the spring represents an environment in which microbes not commonly associated with resistance to ionising radiation have evolved mechanisms that allow them to live in the presence of radon. For example, it will be interesting to determine whether the Paralana cyanobacteria are more radiation-resistant than their cousins in similar, but radiation-free, environments (e.g. Shark Bay in Western Australia, or New Zealand hot springs).

Fortunately, we will soon be able to test this hypothesis. The first author is a member of a NASA team, headed by Dr Lynn Rothschild, which plans to isolate highly radiation-resistant microbes from a number of different extreme environments, including Paralana. The aim of this NASA Astrobiology Institute funded 5 year study is to test the ability of microbes to survive the harsh space environment, which is extremely cold, and is subject to unfiltered solar (uv) radiation, solar wind and galactic cosmic radiation. The most radiation-resistant microbes will be exposed to this environment by flying them in experiments on-board satellites and the International Space Station. The results of this study will be used to test the theory that life can (and has) hitchhiked between solar system bodies, such as Earth and Mars, on objects such as meteorites.

Conclusion

The Paralana hot spring is an intriguing site with astrobiological implications as an analogue for conditions on the early Earth. The research conducted thus far has identified a diverse community of mostly thermophilic microbes. Whilst it is possible that the resident microbial community is unaffected by the radon, we consider this the least likely possibility. More probable is that the microbes have adapted to the environment, having

Figure 2. Differential interference contrast micrograph (wet mount) of a mat composed of filamentous cyanobacteria. This sample was collected from the source pool. Scale bar = 10 µm. Photo ©Roberto Anitori, 2003.
evolved mechanisms that allow them to survive in the presence of ionising radiation. If this is the case, then the NASA collaborative study has a good chance of identifying a highly radiation-resistant microbe. So, remember to occasionally look up into the heavens – that bright streak might just be carrying Australia’s first official ‘micronauts’.

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References