

haematite concretions. As on Mars, the weathering of these rocks causes the concretions to tumble to the ground and spread across the surrounding plains. There the concretions become smooth and shiny from wind abrasion, and their diameters range from millimetres to centimetres. The loose Utah concretions roll like marbles into depressions, forming 'puddles', just like their martian counterparts (Fig. 1).

The host rock for the Utah concretions is Navajo Sandstone. This rock derives from a vast desert of sand dunes that was deposited by trade winds in the Jurassic, when Utah was situated in the tropics. Microscopic iron-oxide films coat the sand grains and impart vivid red and pink colours to the sandstone. Fine iron oxides are reddish, unlike the brownish-black colour of densely cemented iron oxide in haematite concretions. Voids between Navajo Sandstone grains, which were sorted to uniform size by ancient winds, render the sandstone porous like a sponge. Fluids that are reducing, acidic, hot, or some combination of these, can mobilize iron. In certain areas, Navajo Sandstone has been bleached white by groundwater that dissolved the fine iron oxides. Where iron-rich fluids encountered more oxidizing or alkaline microenvironments, iron precipitated and cemented into concretions. But because iron is poorly soluble, large amounts of groundwater were needed — Chan *et al.*<sup>9</sup> estimate 100 kg of water per gram of iron.

How good an analogue are the Utah concretions to those on Mars? There are important similarities, which include the surface accumulations, iron-rich fluids, porous host rock and significant volumes of fluid. But Chan *et al.* also note key differences. Opportunity's spectrometers and camera indicate that the martian haematite is pure, crystalline and grey. In contrast, the Utah concretions are mostly quartz, with brownish-black haematite cement as a secondary component. Consequently, the infrared spectrum that alerted us to haematite on Mars is unlikely to match a quartz-dominated spectrum from the Utah concretions.

Fine-grained Navajo Sandstone is comparable to the fine texture of the sedimentary rocks in Terra Meridiani. But the martian rocks are compositionally quite different and contain up to 40% sulphates, suggesting that they were deposited in an evaporating brine<sup>7</sup>. NASA's rover team has reported the presence of jarosite,  $KFe_3(SO_4)_2(OH)_6$ , which, from thermodynamic considerations, implies an acidic environment (see Box 1). Thus, on Mars it was probably acidic water, rather than the reducing, hydrocarbon-rich fluids inferred for Utah, that mobilized iron. Acidity might have derived from dissolved carbon dioxide, given Mars's  $CO_2$ -dominated atmosphere, but such a fluid would leave behind tell-tale carbonate minerals. The absence of carbonates and

the conspicuous abundance of hydrous sulphates imply that the solution probably contained sulphuric acid.

The Hopi Indians have a legend that 'moqui', or spirits of their ancestors, played games of marbles with the haematite concretions in the American southwest. Although anthropologists discourage use of the word 'moqui', to be respectful to Native Americans, New Age gem collectors sell concretions as 'moqui marbles' and claim that they are endowed with metaphysical powers. New Agers are at least partly correct in their supposition that the haematite marbles can provide answers to the questions that you might ask of them. Given the similarities<sup>9</sup> between the marbles in Utah and on Mars, additional scientific scrutiny of the Utah concretions and how they form will probably shed further light on the similar phenomenon on Mars.

Indeed, if we could bring back concretions from Mars, much could be learned. On Earth, concretions can be valuable indicators of sediment burial history, physico-chemical

conditions, palaeobiology and even palaeoclimate<sup>10</sup>. Moreover, the detailed geochemistry of the sulphate-rich martian rocks would probably prove even more revealing. So perhaps NASA's proposed sample-return mission for 2013 should shoot for Terra Meridiani, and follow the wheel tracks of Opportunity. ■

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Molecular biology

## The loader of the rings

Michael A. Trakselis and Stephen D. Bell

Among the numerous molecular machines involved in the process of DNA replication are the ring-shaped sliding clamp and the clamp loader. Intriguing structural details of their interaction are now revealed.

The double-helical structure of DNA is an icon of our time, appearing almost daily as a backdrop to news stories about medical advances and in myriad sci-fi movies. The molecule itself consists of two inter-wound strands, the backbones of which are composed of alternating phosphate and sugar groups. Extending from the backbone into the heart of the double helix are the bases — guanine, adenine, thymine and cytosine — whose order encodes the information stored by DNA. The bases on one strand must pair precisely with those on the opposite strand, adenine with thymine and guanine with cytosine<sup>1</sup>, and this provides a simple and elegant mechanism for copying this genetic material. The double helix simply unwinds and unzips, with both strands then being used as templates for the enzyme DNA polymerase, together with a large assembly of accessory factors, to make two daughter DNA molecules. Papers published on page 724 of this issue<sup>2</sup> and in *Nature Structural and Molecular Biology*<sup>3</sup> now add to our understanding of a crucial molecular contributor to this process.

Because of a chemical asymmetry in the arrangement of DNA, one daughter strand, termed the leading strand, is synthesized continuously during DNA replication. The

other, the lagging strand, is made in short segments (called Okazaki fragments) that are later joined together. Central to this process is the sliding clamp, a ring-shaped, multi-subunit molecule that encircles the DNA and binds to the DNA polymerase. As the name suggests, the sliding clamp can slide along DNA, and so provides a mechanism for tethering the DNA polymerase to the template. On the leading strand this is extremely important, because the polymerase might have to continue synthesizing DNA for more than a million bases. But the clamp is also important on the lagging strand, because several of the factors involved in processing the Okazaki fragments use it as a scaffold for their assembly<sup>4</sup>.

The ring-shaped nature of the sliding clamp presents a simple topological problem: how is DNA introduced into the hole in the clamp's centre? This is the job of a complex molecular engine termed the clamp loader, which must somehow open the sliding clamp, pass DNA into the ring and then reseal it. These requirements are a common theme in several DNA-based processes. Higher organisms, for instance, also possess a DNA-repair-specific sliding clamp and clamp loader, and it is likely that similarities will be found in earlier stages in the

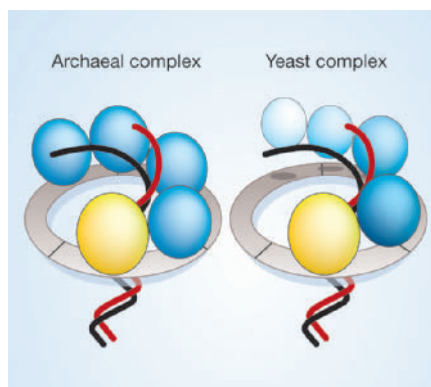
replication process, when the DNA-unwinding helicase proteins are loaded.

Bowman *et al.*<sup>2</sup> and Miyata *et al.*<sup>3</sup> now offer new insight into the clamp-loading reaction, through structural analyses of the complexes formed between a sliding clamp and its cognate clamp loader in yeast<sup>2</sup> and in the archaeon *Pyrococcus furiosus*<sup>3</sup>. The clamp loader in question is named replication factor-C (RFC). In yeast, RFC has one large subunit and four smaller components with related sequences; in archaea (microbes that have a simpler replication machinery than yeast), it has one large and four identical small subunits. The sliding clamp, meanwhile, is named proliferating cell nuclear antigen (PCNA) and consists of three identical subunits.

It has been known for many years that RFC can, in the presence of the high-energy cofactor adenosine triphosphate (ATP), mediate the loading of PCNA onto DNA<sup>5,6</sup>. The RFC clamp loader then hydrolyses the ATP, resulting in the clamp being handed off to DNA polymerase. Taking advantage of the fact that a stable complex can be formed between DNA, PCNA and RFC in the presence of a poorly hydrolysable ATP analogue, Miyata *et al.*<sup>3</sup> were able to purify such a complex from *Pyrococcus* and subject it to electron microscopy followed by three-dimensional reconstruction.

The resulting image is intriguing. The structure resembles a horseshoe stacked on a doughnut (Fig. 1), with the doughnut corresponding to the clamp, PCNA, and the horseshoe to the clamp loader, RFC. It seems as though the large subunit of RFC contacts one subunit of PCNA, and two or three of the RFC small subunits contact the remaining two PCNA subunits. DNA passes through the PCNA ring and emerges through the open channel in the horseshoe of RFC. Thus, this structure presumably corresponds to the loaded complex, just before PCNA binds DNA polymerase.

Meanwhile, Bowman *et al.*<sup>2</sup> describe a stunning, high-resolution atomic structure of yeast RFC in complex with PCNA, again in the presence of a poorly hydrolysable ATP analogue. In this case, DNA was not present in the crystallized complex itself but was incorporated in the three-dimensional reconstruction. As in the archaeal image, RFC sits on top of PCNA, with the large subunit contacting one PCNA subunit. But there are some important differences in the interactions of the RFC small subunits. Most significantly, instead of lying flat on PCNA, contacting the remaining two PCNA subunits, the RFC small subunits spiral up and away from the plane of the PCNA ring and contact only one further PCNA subunit (Fig. 1). Remarkably, the pitch of the spiral produced by RFC matches the geometry of the DNA double helix, and the authors present a persuasive model for how the subunits



**Figure 1 Clamping down on DNA.** The new papers<sup>2,3</sup> describe the structures of the yeast<sup>2</sup> and archaeal<sup>3</sup> clamp-clamp-loader complexes; the similarities and differences are depicted here. The sliding clamp, PCNA, is in grey. The clamp loader, RFC, is shown as a series of coloured ovals, with the large subunit in yellow and the small subunits in blue. The yeast small subunits have distinct but related sequences (indicated by graded colours); the archaeal small subunits are identical. The predicted path of DNA through the complex is also shown, with the template strand in black and the new strand in red.

might contact the DNA so as to direct loading.

So why is there this difference? Setting aside trivial explanations of species differences or methods of sample preparation, could it be that these two complexes represent distinct stages in the clamp-loading process? Might the archaeal structure represent the initial complex and the yeast one a later stage? If so, might the differences arise

by virtue of an isomerization of RFC that occurs before ATP is hydrolysed and PCNA is handed over to DNA polymerase? And could the fact that one subunit of PCNA is exposed in the yeast structure therefore be indicative of the route that the DNA polymerase takes to access the ring? Finally, it remains to be seen how RFC actually opens the PCNA ring. Might the spiral of RFC subunits indicate that this clamp loader pries PCNA open by pulling a subunit or subunits out of the plane of the ring, popping it open like a lock washer? Or does RFC wrench PCNA open within the plane of the ring, creating a horseshoe structure that mirrors its own?

These structures provide exciting snapshots of the manner in which RFC and PCNA interact. Although small differences have been identified, conserved themes in this essential reaction are coming to the fore. With continuing efforts to study other stages of clamp loading, a full molecular view of the process seems to be on the horizon. ■

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### Laser physics

## Fantastic plastic

by D. W. Samuel

Plastics are ubiquitous, thanks to the cheapness and versatility of these materials. Now plastic lasers are in prospect, battery-operated for low-cost communication and display applications.

Nearly all plastics are electrical insulators, but one class of plastics is different. These are conjugated polymers, whose discovery was celebrated with the award of the 2000 Nobel Prize in Chemistry. They differ from other polymers in having a backbone of alternating single and double bonds, and this difference in structure makes them semiconductors. Conjugated polymers are therefore interesting materials, with their unique combination of semiconducting properties and scope for simple fabrication and shaping. Lasers are a promising application, and now Reufer *et al.*<sup>1</sup>, writing in *Applied Physics Letters*, report fresh progress towards the creation of low-cost polymer lasers.

A major breakthrough in the development of semiconducting polymers was the

discovery that when a voltage is applied to a thin layer of one of these materials, light can be emitted<sup>2</sup>. Light-emitting diodes using this effect are now the basis of a modern flat-panel display technology. Other polymer optoelectronic devices have followed, including polymer solar cells, optical amplifiers and lasers, although further development is necessary before they reach the market. Polymer lasers are attractive as light sources for several reasons. Polymers can emit light across the visible spectrum, and so wavelengths can be generated that are not readily available from other lasers. The polymers have broad spectra, meaning that a polymer laser can be tuned over a range of wavelengths. Polymer lasers should also be simple to make, can be flexible, and should