in some oil fields.

Flow by diffusive mass transfer involves transport of matter from grain boundaries subjected to a high normal stress to grain boundaries which are less highly stressed. If the diffusion is predominantly through the grains, the process is termed Nabarro-Herring Creep, whereas if it is predominantly around grain boundaries, the flow is called Coble Creep. In general, grain boundary sliding must occur to accommodate the grain shape changes due to diffusion. These processes only proceed at a detectable rate, when the temperature is a large fraction of the absolute melting temperature of the material. Whereas processes involving solid state diffusion probably occur in high grade metamorphic rocks and in the mantle, geologists have long recognised that textures such as tectonic stylolites, truncated fossils and tectonic overgrowths in low grade metamorphic rocks often indicate deformation by diffusive mass transfer. Even over the relatively long time available for geological deformations, solid state diffusivities would be too slow to account for the observed strains. It is therefore inferred that the rate of diffusive mass transport is enhanced by the presence of an intergranular fluid film—hence the term pressure solution. Thus Coble Creep and pressure solution are geometrically similar in that they both involve intergranular diffusion.

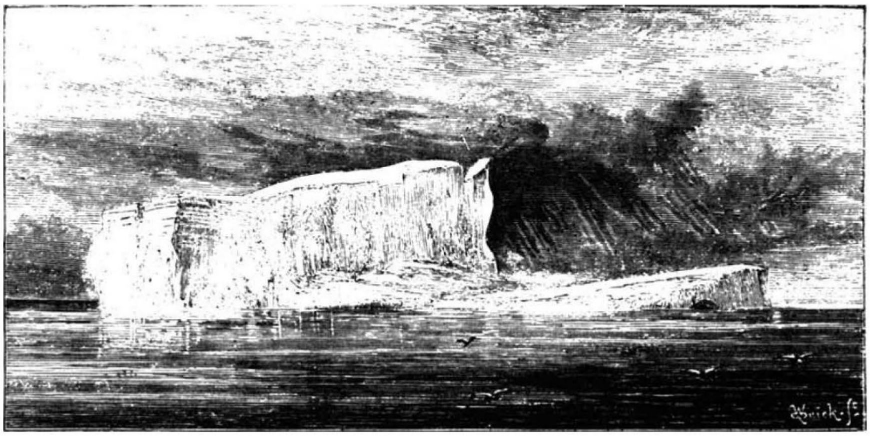
E. Rutter (Imperial College) demonstrated that Coble Creep and pressure solution have similar flow laws (for a review see Rutter, *Phil. Trans. R. Soc. Lond.*, **A283**, 203; 1976), and indicated that the rate of diffusive mass transfer is generally considered to be the rate-controlling step during deformation. Rutter also emphasised the importance of recognising the several possible diffusion paths in low grade metamorphic rocks (R. Knipe, Imperial College). This research indicates that in some sandstones, intracrystalline diffusion along subgrain walls may be able to give rise to strain rates equivalent to those for pressure solution along grain boundaries. Stress relaxation experiments (E. Rutter and D. Mainprice, Imperial College), clearly showed the strong influence of pore water on the creep behaviour of Tennessee sandstone. They inferred that this behaviour indicates deformation by grain boundary sliding accommodated by diffusive mass transfer. In a review of the field evidence for pressure solution (such as striped cleavage, tectonic stylolites, and truncated fossils), J. Ramsay (University of Leeds) indicated that two types of pressure solution regimes occur; an isochemical regime where precipitation of the dissolved phase occurs close to the generating interface (giving pressure shadows and overgrowths) and a regime where the bulk chemistry is changed because the dissolved material is precipitated elsewhere (giving tectonic veining). The influence of stress 'risers' which produce variations in the mean stress was considered important in the initiation of pressure solution seams.

M. Casey (University of Leeds) has formulated a purely solid state, Coble Creep finite element model for diffusion over several grain diameters (that is, Ramsay's second regime). Applying this to a study of differentiation in microfolds and crenulations he has concluded that fluid-assisted diffusion is necessary to account for these microstructures. B. Burton (CEGB Laboratories, Berkeley) discussed the available data on Coble Creep in metals and ceramics, and emphasised that this may not be an important deformation mechanism at low stresses and low homologous temperatures because of the stress needed to create sources and sinks for vacancy diffusion.

R. De Boer (Shell Laboratories, Rijswijk) pointed out the difficulties in experimental investigations of pressure solution. The process is intrinsically slow and cannot be speeded up because of the low heat of activation, and also the difficulty in suppressing plastic deformation and cracking.

In experimental simulation of oil reservoir phenomena, he has found that pressure solution phenomena occur in quartz sands above 280 °C and in carbonate mixtures at 200 °C. An important report of recent research involving fluid inclusion geothermometry and oxygen isotope studies was given by R. Kerrich (University of Western Ontario). He suggested that grain size greatly influences pressure solution processes and that these processes are important in the deformation of fine-grained quartz and carbonate rocks at low metamorphic temperatures. A lively discussion was generated by the contribution of A. Beach (University of Liverpool) who considered that many of the residue minerals in pressure solution seams are in fact the products of prograde metamorphism. Metamorphic reactions could produce the silica found in the tectonic veins common in low grade metamorphic environments.

Over the past decade much data has been collected and many significant advances made, and there has been a convergence towards detailed microstructural, isotopic and chemical studies of natural pressure solution systems. Although only limited success has been achieved so far in experimental work, stress relaxation tests will allow access to the slow strain rates which are not attainable in normal triaxial tests. Grain size effects are very important and careful consideration of the various possible diffusion paths must be made. Many questions still remain unanswered, however, particularly about the origin of the periodicity of pressure solution seams and striping. Many research programmes are being pursued however, and these will undoubtedly produce results which will not only be of great academic interest but also of significance in the interpretation of some fault behaviour, and compaction behaviour of oil field reservoir rocks. □



A hundred years ago

WE frequently saw table-topped icebergs with the upper surface very irregular; when that is the case evidence may usually be found from the colour, the closeness of the veining and other appearances that it is not the original surface of the iceberg which is now presented to us, but a second surface produced by cutting away by the sea of an entire story, as it were, of the berg; which although it had no doubt at one time during the process been greatly inclined, had recovered its equilibrium on the whole of the upper layer having been more or less symmetrically removed. (Conditions in the Antarctic: from a lecture given by Sir Wyville Thomson in Glasgow.)
From *Nature*, **15**, December 7, 120; 1876.