Physical resources

Surprise in store for coal burning (*January 2011*)

Australian open-cast coal mining Wikipedia

Coal has long been assumed to be the most plentiful of the fossil fuels, even the most pessimistic forecasters having acknowledged a global lifetime of centuries for known reserves. The determination of the emerging giant economies of China and India and of the USA to fuel themselves through coal-burning seems inevitable if highly risky for the climate. But that depends on coal remaining the cheapest fuel, largely because of the sheer abundance of supplies. A recent commentary on coal (Heinberg, R. & Fridley, D. 2010. The end of cheap coal. *Nature*, v. **268**, p. 367-369; DOI: 10.1038/468367a) suggests that there is a growing tendency for reserve estimates to decrease as geologists factor in practical restrictions – place, depth, seam thickness and quality – on feasibility under current mining conditions, instead of just looking at known masses of coal. Astonishingly, the end-19th century estimate of five thousand years of US coal supplies dropped to about 400 years by 1974 and is currently judged to be 240 years. China and India look likely to have less than 60 years-worth left. On top of that, the widely publicized turn to carbon capture and storage (CCS) for 'clean-coal' future supplies will inevitably drive-up prices of coal-fired energy. The two main factors in this remarkable transformation of 'King Coal' are fundamental economic forces in capitalism and the increasing refusal of miners to accept dangerous working conditions. The second is especially the case for China, where most coal is deep-mined; in the late 1990s it saw a drive to close down unsafe mines that caused production to fall, although it has greatly accelerated this century – further driving down coal's lifetime there. It seems from this analysis that any realistic hope for a CCS-based coal economy, especially in China and India, depends on declining safety and environmental standards in their largely underground mines, which in turn depends on the highly unlikely willingness of their workforces to accept worse conditions.

Gold, magma and groundwater in Nevada (*March 2011*)

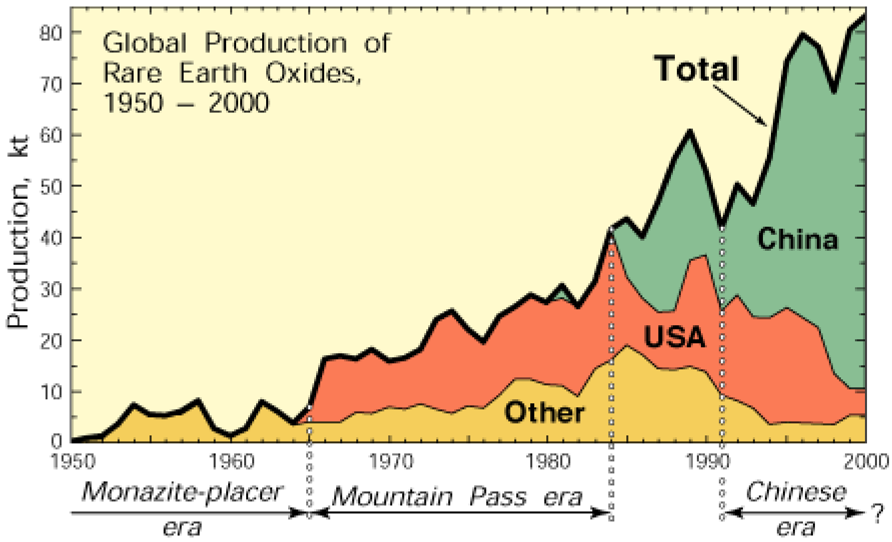
With the price of gold having climbed to above \$1400 oz^{-1} during the 'Arab Spring' upheavals, articles on how gold deposits form will get a wider readership than they would have during its doldrum years in the late 20th century – the price has increased 7-fold since 2000. The bulk of gold nowadays can be mined profitably from ores in which it cannot be seen, except using a microscope, at grades well below 1 g t^{-1} (1 part per million) thanks to cheap heap-leaching with sodium cyanide of lightly milled ore. The epitome of low-grade gold is that produced at huge open-pit mines in Nevada from sedimentary host rocks. The gold is far too fine grained to have been deposited as placers, and also occurs dissolved in pyrite (Fe_2S), so most experts regard it as having been introduced by hydrothermal fluids. Yet that covers two possibilities: by deep penetration of groundwater or from magmatic waters, and it is hard to decide which, again because the mineralisation is too fine grained to allow conclusive studies of fluid inclusions and stable isotopes. Also, such evidence as there is suggests low temperature fluids (~200° C) with low salinity; ambiguous data.

By using a synergy of ore-mineral chemistry, experimental data and ages of magmatism and mineralisation, Nevadan geologists have developed a convincing model for these 'Carlin-type' deposits (Muntean, J.L. *et al*. 2011. Magmatic-hydrothermal origin of Nevada's Carlin-type gold deposits. *Nature Geoscience*, v. **4**, p. 122-127; DOI: 10.1038/NGEO1064). First, the mineralisation is of Eocene age and was introduced in Lower Palaeozoic sediments. The Eocene in the western USA saw the end of a period of compressional tectonics related to subduction since the Jurassic, fluids from which gave rise to partial melting of the overlying mantle wedge. This was succeeded by extensional tectonics and further intrusive magmatism dated between 40 to 36 Ma. This provided thermal energy and passageways for fluid migration. The second line of evidence is that hydrogen- and oxygen isotopes from fluid inclusions in hydrothermal gangue minerals show evidence that both mantle-derived and meteoric water mixed in the ore-forming fluids, and sulfur isotopes are similarly evidence of dual origin. Thirdly, the authors reasonably postulate from experimental data that basaltic back-arc magmas of Jurassic to Eocene age may have repeatedly added metals, including gold, to the mantle wedge that underpinned Nevada during subduction over a 175 Ma period.

Thus later extension-related magmatism sourced in the wedge would itself have become metal enriched from this 'fertile' source. Moreover, conditions would have been ripe for highly oxidised conditions in the magmas and high concentrations of water in their fractionated descendants. Under such conditions gold and other metals favour entry into hydrothermal fluids. Given the extensional tectonic conditions such fluids could rise efficiently. Initially highly saline and very hot, rapid rise of the fluids would eventually result in them cooling adiabatically and separating into a dense salty liquid or brine and remaining vapour. That would force down the chlorine content in the vapour, favour some metals (Fe, Ag, Pb, Zn and Mn) ending up in the brine, while others (Au, Cu, As and Sb together with S) would remain in the vapour phase together with dissolved CO_2 in large amounts, making the vapour acidic. Able to pass into the fractured Palaeozoic cover, the fluids widened fractures in the carbonate sediments and facilitated their own precipitation of minerals, the foremost being gold-bearing pyrite. Nevada is probably unique. But, my goodness, it's a big gold province; >6000 t of gold in them their hills.

Hi-tech future may be saved by ocean floor sediments (*September 2011*)

Since the 1968 founding of the Club of Rome and the re-emergence of Malthusian ideology, time and again there have been warnings about the imminent running out of resources that are essential for modern life. The latest concern one of the formerly haunted wings of the Periodic Table, central to petrogenetic geochemistry, but little else; the rare-earth elements. From early beginnings as the source for phosphors in the screens of colour televisions all 15 REEs now have a growing commercial role in applications ranging from precision guided weapons, night-vision goggles and stealth technology in the military sphere, through the satiation of artificial appetites for electronic gaming and mobile phones, to applications of super-efficient magnets in medial scanners and 'green' power generation. The crisis being discussed currently is not so much a shortage – REEs are not so rare – but the cornering of their mining by the Peoples' Republic of China, which produces more than 95% of RREs used at present (~120 thousand tons). Yet world reserves are estimated at almost 100 million t, of which China has 36 million. Mining is dominated by a few known, high-grade deposits; for instance most of the US reserves of 13 million t are locked in the Mountain Pass Mine, California that is currently on a 'care-and-maintenance' regime, i.e. shut. This one-sided economy sends shudders through capital's strategy forums, i.e. in the US, Silicon Valley and the Pentagon.



China's growing REE market share (Credit: Wikimedia)

Not surprisingly, geochemists and oceanographers from Japan, the world's most hi-tech country, have bent their collective will to finding alternative sources, and may have revealed one in an unexpected location (Kato, Y. *et al*. 2011. Deep-sea mud in the Pacific Ocean as a potential resource for rare-earth elements. *Nature Geoscience*, v. **4**, p. 535-539; DOI: 10.1038/ngeo1185). Their work stems from 'mining' existing geochemical data from deep-sea drilling projects on the floor of the Pacific Ocean, that reveal a wide range of REE concentrations in the ooze coating the seabed: from <250 to >2000 parts per million. The richest pickings seem to lie in a swath either side of the East Pacific Rise at around 15°S, where the group estimate that a 1 km^2 plot could yield about one fifth of current world annual production, even though REE concentrations lie way below their on-shore economic cut-off grade. Apart from the need for dredging at depths around 3-5 km on the abyssal plains, and the inevitability of destroying a largely unknown ecosystem, the positive aspect of these metal-rich oozes is that the REE can be extracted simply by acid leaching of the goethite (FeOOH) in which the bulk of the elements reside. Goethite is something of a geochemical ‘mop’ with a capacity for adsorbing elements of all kinds on grain surfaces; so much so that it is being considered as a means of cleaning up heavy-metal pollution. Both the REEs and the iron probably arise from seabed hot springs where oxidising conditions result in dissolved ferrous iron combining in ferric form with oxygen to form goethite, which in turn scavenges other dissolved ions. Many of the on-shore REE deposits are carbonatites (intrusions of carbonate-rich magmas) that contain fluoro-carbonates and phosphates that host the REE, or beach sands in which wave swash concentrates the durable heavy phosphates in so-called black-sand deposits. Carbonatites are rare, most occurring in ancient ‘shields’, as in southern Africa, Canada and China, but being so unusual are not difficult to find. One in the Canadian Shield known as the Big Spruce Lake deposit provides phosphorus- and potassium-rich soil that encourages the growth of conifers and so creates a geobotanical anomaly of large trees where local climate generally supports only stunted ones.

The rising demand and currently restricted supply of REEs is creating an exploration boom for carbonatites as the metal prices rise inexorably. Yet it may also produce a shift to what seems to be an alternative kind of source; iron-rich deep-sea sediments, though more likely those preserved on-shore in ophiolite complexes than at the huge depths of the abyssal plains. It is worth bearing in mind, however, that oceanographers and geochemists have pointed to untold metal riches before: manganese nodules that litter huge tracts of the seabed and contain sufficient copper, nickel and cobalt to maintain supplies for millennia. Despite a half-billion dollar investment in the 1960s and 70s, there is no nodule-dredging industry. There are however well-advanced plans for deep water mining of gold-rich hydrothermal sites, but miners will go just about anywhere to gloat over Marx’s ‘money commodity’.

Britain to be comprehensively fracked? (*October 2011*)

In ‘*Fracking’ shale and US ‘peak gas’* (July 2010) I drew attention to the relief being offered to dwindling US self-sufficiency in natural gas by new drilling and subsurface rock-fracturing technologies that opens access to extremely ‘tight’ carbonaceous shale and the gas it contains. The item also hinted at the down-side of shale-gas. The ‘fracking’ industry has grown at an alarming rate in the USA, now supplying more than 20% of US demand for gas. This side of the Atlantic the once vast reserves of North Sea gas fields are approaching exhaustion. This is at a time when commitments to reducing carbon emissions dramatically depend to a large extent on hydrocarbon gas supplanting coal to generate electricity, thereby releasing much lower CO_2 by burning hydrogen-rich gases such as methane (CH_4) than by using coal that contains mainly carbon. Without alternative, indigenous supplies declining gas reserves in Western Europe also seem likely to enforce dependency on piped gas from Russia or shipment of liquefied petroleum gas from those major oil fields that produce it. The scene has been set in Europe in general and Britain in particular for a massive round of exploration aimed at alternative gas sources beneath dry land. Unlike the US and Canada, the British are not accustomed to on-shore drilling rigs, seismic exploration and production platforms, and nor are most Europeans. Least welcome are the potential environmental and social hazards that have been associated with the US fracking industry, which seem a greater threat in more densely populated Europe.

The offshore oil and gas of the North Sea fields formed by a process of slow geothermal heating of solid hydrocarbons or kerogen in source rocks at a variety of stratigraphic levels. The escape into surrounding rocks of the gases and liquids produced by this maturation, and their eventual migration and accumulation in geological traps is what produces conventional resources. But by no means all products of maturation leave shale source rocks because of their very low permeability. That residue may be much more voluminous than petroleum liquids and gases in conventional reservoir rocks; hence the attraction of fracking carbonaceous shales. British on-shore geology is bulging with them, particularly Devonian and Carboniferous lacustrine mudstones, Carboniferous and Jurassic coals, and the marine black shales of the Jurassic (see http://www.bgs.ac.uk/research/energy/shaleGas.html and https://www.og.decc.gov.uk/upstream/licensing/shalegas.pdf), to the extent that areas of potential fracking cover around a third of England, Wales and southern Scotland.

News is breaking of a major shale-gas discovery beneath Blackpool, the seaside resort 'noted for fresh air and fun...', and also said by energy firm Cuadrilla to have gas reserves of 5.7 trillion m^3. The announcement followed 6 months of exploratory drilling, and drew attention to the burgeoning interest by entrepreneurs in the upcoming 14th Onshore Licensing Round for petroleum exploration in Britain. It isn't just from major petroleum companies, but in some cases even what amount to family businesses finding sufficient venture capital to spud wells; similar in many respects to the US fracking boom.