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The Golem at Large

what you should know about technology

Harry Collins
Trevor Pinch

CAMBRIDGE
UNIVERSITY PRESS

4

The world according to Gold: disputes about the origins of oil

Every schoolchild sooner or later learns the standard story of the origins of oil; it runs something like this. Once upon a time, hundreds of millions of years ago, the earth was covered by vast oceans. Animals, plants and micro-organisms in the seas lived and died by the billion, their remains sinking to the bottom and mixing with sand and mud to form marine sediment. As the ages passed, the mud turned to rock and eventually the organic mass became buried deep under layers of rock. The oceans receded and the earth's crust heaved and buckled. Compressed under this vast weight of rock, decomposition occurred and the layers of biomass underwent a chemical change to form hydrocarbons (compounds composed only of hydrogen and carbon atoms) – coal, oil, and natural gas.

Special geological conditions are needed to keep the oil trapped underground. The organic material has to be covered by porous rocks and these, in turn, have to be covered by an impermeable layer which acts as a cap to prevent the oil and gas escaping. Oil is consequently found only in places where these geological conditions are met.

Although this crude, even mythical, account has become greatly more refined in modern petroleum geology, the underlying tenet that oil is formed by biological decay is the starting point for any exploration of the subject. And we all know that there are good reasons why oil is called a *fossil fuel*: the large numbers of fossils found in and alongside coal, and the micro-organisms found in oil are taken to demonstrate their organic origins.

Perhaps the most compelling reason to believe that we have it right as regards the origins of oil is the commercial interests involved. There is a giant petro-chemical industry which derives its profits

from mining and refining 'black gold'. Oil is at the roots of our modern industrial civilization. It is not some esoteric sub-atomic particle upon which a few physicists have built their careers. When we talk about oil we are talking about no less than the history of the modern world. A vast industry supported by national governments makes sure it understands *how* oil is found, *where* it is found and *who* has the rights to find it. Surely, if all this effort has made us so rich, we must be smart. Or are we?

There is one man on the planet who seriously thinks we have it wrong. His name is Thomas Gold.

GOLD'S WORLD

The world according to Gold is actually not that different from the world we know. Oil would still be found in all the places where it has already been discovered, it is just that there would be more of it, and it would be located in more places. According to Gold, we are wrong about how oil is formed. Oil is not the result of biological decomposition, but is produced non-biologically, or 'abiogenically'. When the earth was first formed, primordial hydrocarbons were trapped deep under the surface. These primordial hydrocarbons, by a continuous process of 'outgassing', have gradually and continuously migrated to the surface. The oil discovered so far is only that which is most accessible. There are, according to Gold, other reservoirs, of vast extent, waiting to be discovered deep below the surface. Even more importantly, in the world according to Gold, oil should be found in places where, according to the standard theory, there should be none. If Gold is right, countries apparently bereft of oil could be sitting upon huge reserves. The geo-political implications would be enormous.

The non-biological theory of the origins of oil has a long history. In the late 1870s, the Russian chemist, Dmitri Mendeleev, best known as the inventor of the periodic table of elements, rejected the, then current, biological theory of the origins of oil and proposed an abiogenic theory. Mendeleev's ideas received wide currency at the time, but as twentieth century geology developed his theory started to lose credence. Since the 1940s nearly all geologists have accepted the biogenic theory. The very tiny group of dissenters has Gold as its

most vocal supporter, but also includes some Chinese geologists, some Swedes, Gold's collaborator Stephen Soter, and the oil prospector Robert Hefner III.

WHO IS GOLD?

If Thomas Gold did not exist he would have to be invented. Throughout his distinguished career he has made a habit of entering new fields, ruffling old feathers, and on the way he has laid a surprisingly large number of scientific golden eggs. Gold was born in Austria before moving to Switzerland where he studied physics. He then emigrated to Britain to continue his education at Cambridge University. He worked on radar during the Second World War, then moved to the US where he has spent almost his entire active scientific career. He is a Fellow of the Royal Society and a member of the US National Academy of Sciences.

It was Gold who first came up with the term 'magnetosphere' and did much of the early research on it. More famously, he was part of the team that produced the steady state theory of cosmology (Fred Hoyle being the better known part of the partnership), that for years was taken as a serious rival to the 'big bang'. Long before biophysics became a popular subject, he treated the human ear as an active receiver. Most stunning of all, he was the scientist who first proposed that pulsars were collapsed neutron stars. Gold claims his colleagues denied him speaking time at a conference on pulsars when he first came up with the idea; within a year the rest of the scientific community were proved wrong and Gold's paper on pulsars has become a classic. In between these interventions into other fields, Gold does some, by his own standards, quite ordinary things. Indeed, Gold himself contends that the vast majority of his work is mainstream, widely accepted and widely shared; only in these high-publicity incidents has he been on the fringe. Gold accepted a professorship at Cornell University in 1959 and went on to oversee the construction of the world's largest radio telescope at Arecibo, Puerto Rico. Today Gold is as active as ever and holds an emeritus professorship in Space Sciences at Cornell University.

There is no doubt that Gold is widely respected for his scientific

abilities. As one scientist, who is otherwise completely scathing about Gold's work in geology, remarked:

> Thomas Gold is, by the way, a very imaginative and wonderful scientist.
>
> *(Cole, 1996. p. 736)*

Another commented:

> Tommy has had many extraordinary ideas that are not in the mainstream, and very often they've proven to be correct . . . He's just very, very, good.
>
> *(p. 737)*

Gold is known for his debating prowess and charisma:

> In fact, no one from this side can successfully debate Gold. I shouldn't put it that way. I think people debate Tommy, but Tommy is really a very persuasive person. It's just his arguments are not persuasive to people from the earth science discipline in general.
>
> *(p. 738)*

Or as another person sceptical of Gold's abiogenic theory declared:

> I wish I could put across what I believe is right as well as Tommy Gold can put across what I believe is wrong!
>
> *(p. 738)*

WHICH CAME FIRST, THE FOSSIL OR THE FUEL?

For any non-biological theory to be taken seriously it must be able to explain why organic molecules and other evidence of organic life are found in oil. It is here that Gold, rather than being put on the defensive, can claim support for his ideas.

Geomicrobiology, the study of subterranean bacterial life, is one of the newest and most exciting fields of science. Microbes have been found living in the most unlikely of places, like geysers, deep ocean vents and even oil deposits. They live at improbably high temperatures (up to 115 °C), improbably great depths (down to 5 kilometres), and they feed off improbably poisonous compounds such as sulphur and arsenic. There is, then, life a thousand leagues under the sea.

This life has left traces, traces which Gold uses to bolster his

abiogenic theory. The 'biological marker molecules' or 'hopanoids' found in petroleum are usually taken to be one of the central planks supporting the biogenic theory. How could these extremely complex organic molecules have got into petroleum unless petroleum is itself the product of some sort of organic decay? Gold holds that these molecules, rather than being the remnants of ancient terrestrial life, are the traces of a living subterranean biosphere which uses petroleum as a chemical energy source. For most geologists the fossils feed the fuel, but for Gold, the fuel feeds the fossils.

Gold has recently (1997) linked his theory of biological life deep within the earth's surface to the controversial claims to find traces of microbiological life in a Martian meteorite. According to Gold's theory, micro-organisms metabolize hydrocarbons and they can do it, not only within the earth, but also on other planets. Gold told the 1997 meeting of the American Association for the Advancement of Science, 'Down there, the earth doesn't have any particular advantage over any other planetary body'. He went on to point out that there are at least ten other planetary bodies that have enormous amounts of hydrocarbons in their atmosphere.

As is often the case, this scientific controversy over the abiogenic origins of fossil fuels is not a straight two-party fight between Gold and his critics in geology. Other disciplines are involved. It turns out that the microbiologists, unlike the earth scientists, are somewhat more receptive to Gold's theory. Unlike their colleagues in geology they do not have a direct stake in how oil is formed. As one microbiologist put it:

> He's obviously threatening the general community of petroleum geochemists who have built up a whole discipline on the basis of certain hypotheses which he's trying to tear down. And that can be very threatening. And that's most likely the reason for resistance there. From my point of view as a microbiologist what he's proposing is not at all threatening. It's much more like 'well, let's find out more about that, if we can'.
>
> *(Cole, 1996, p. 744)*

Gold himself acknowledges the strategic importance of enlisting the support of the microbiological community and thus in making a run into the end zone around the geologists.

> . . . it will sort of outflank them a little because once this view becomes generally accepted, that there is very widespread life below us, then, of course, they will eventually understand that the argument about the biological origin of oil has been greatly undermined by that. Or destroyed. So, yes, it does outflank them, but with a benign audience.
>
> *(p. 744)*

Gold's strategy here also draws upon the one great revolution that the earth sciences have experienced – and one which still embarrasses many geoscientists – plate tectonics. This is the idea that the continents once formed one big land mass which, over the aeons, slowly drifted apart. The theory was only accepted in geology after being ignored and resisted for decades. Alfred Wegener, the chief proponent of plate tectonics, was often dismissed as a climatologist who had no business doing geology. Wegener enlisted the support of people from peripheral disciplines. For example, palaeontologists who noted similarities between the species found in West Africa and in the eastern part of Latin America were able to provide crucial support to Wegener, thus piquing the geologists:

> Wegener in proposing Drift in effect also proposed a redefinition of geology and a reconstitution of the disciplinary field which included elements of what were otherwise considered heterogeneous bits of disparate disciplines; e.g. geophysics, biogeography, climatology and palaeobotany, and which moved these from the wings to the center stage.
>
> *(p. 744)*

Geologists are sensitive to the comparison between Gold and Wegener, but Gold's evidence has not convinced them and unlike Wegener's has not got better over time. As one petroleum geologist remarked:

> We often feel guilty that we once were wrong, so we may be a second time wrong. So we should be very, very careful about rejecting things which seem to us ridiculous, but the big difference between Wegener and Gold is Wegener had geologically very good evidence for his hypothesis.
>
> *(p. 737)*

Part of the reason geologists feel so confident that they have it right

comes from simple ideas to do with the porosity of rock and its permeability to oil. Given that rock deep under the surface is under great weight from the rock above it, it is difficult to understand how the rock could be porous enough or permeable enough to allow fluid flow to, say, fill a well drilled deep underground (as we shall see later, oil found in deep wells forms a crucial part of Gold's case). Although there have been anomalous flows of fluid (water) reported in deep wells it is difficult to understand how these could be sustained over geological time periods.

ABIOGENIC EVIDENCE?

What evidence does Gold have?

Doing science on the origins of oil will always involve drawing large conclusions from small amounts of evidence. Events that occurred millions of years ago must be reconstructed. In some ways it is easier to delve into the first few nanoseconds of the universe than to reconstruct something buried deep in the core of the earth. There is an asymmetry between our ability to look outward from earth through nearly empty space and our ability to look inward. We have no direct equivalent to the telescope for looking through solid matter and hence we must surmise what happened millions of years ago from the comparatively thin surface crust to which we have access and from evidence from volcanoes and earthquakes which reveal tantalizing glimpses of what lies below. Although seismic, gravity, and magnetic data, along with inertial measurements tell us something about the earth's deep interior they do not provide such compelling evidence as Galileo obtained from the heavens by simply pointing his telescope at the moon and planets.

Gold claims that when the earth formed, 4.5 billion years ago, hydrocarbons accumulated as solids. They have since slowly seeped up through the mantle in vast quantities to the surface via 'outgassing'. The presence of hydrocarbons on other planets in the solar system is claimed by Gold as one of his most telling pieces of evidence. Since these other planets have never, as far as we know, hosted an active ecosphere, their hydrocarbons are presumably of a

non-biological origin. Why should terrestrial hydrocarbons have been formed in a different way?

Geologists, in response, point out that the hydrocarbons found on other planets are mostly methane. They have known for a very long time that traces of methane are found in volcanoes. So for them there is no mystery about the source of the methane found on other planets. Methane may well be formed deep within the earth, but methane is not crude oil.

Often oil is found in one geographical region despite differences in the geological and topographical terrain and the age of the rock. The simplest explanation, according to Gold, is not oil-producing conditions repeating themselves over time in the same place, but a deep-seated source of the oil. This seepage to the surface could be a cause of earthquakes and explain why historically they are associated with fires, flares and petroleum odours. The upward percolation of oil and gas also explains anomalies in the amounts of trace metals found in oil and the disproportionally high concentration of helium-three found in natural gas – these elements originate from deeper in the core according to Gold's theory.

Again we must stress here that Gold's views are highly unorthodox. One geologist has pointed out that no one on the highly regarded USGS Earthquake Prediction Board supports Gold's ideas on the causes of earthquakes. Also the standard response is that helium-three is a much more mobile gas than methane and hence finding anomalous amounts is not that surprising.

Furthermore, Gold is regarded as someone who lacks experience in geology. The geologists can cite an enormous body of literature and evidence, all supporting the biogenic theory.

A CRUCIAL OIL WELL?

The debate seemed interminable until, in 1985, Gold came up with something which had the potential to settle matters for all time. He proposed a crucial experiment. The most direct way to test the abiogenic theory would be to drill an oil well in a place where there was no sediment and where no oil should be found. If oil was found, then in classic Popperian style, the biological theory of oil would be

falsified. Finding oil would surely, if nothing else, be a clean-cut piece of evidence. As Gold remarked, '[It] was just such a clean case'(Cole, 1996, p. 745).

In 1985, at Gold's urging, the Swedish National Power Company, Vattenfall, agreed to begin oil exploration in the Siljan Ring, a giant meteor impact crater in a huge mass of granite in the middle of Sweden. In the summer of 1987 the first well, Gravberg-1, was drilled. Much to everyone's surprise one hundred litres of black oily gunk was pumped out along with some methane. Had Gold, by finding this small amount of oil-like substance in a place where none should be found, refuted the biogenic theory?

Unfortunately for Gold the process of falsifying theories is not as straightforward as some thinkers would have it. As soon as the oily gunk was found, supporters of the biogenic theory came up with a new interpretation of what had gone on. They argued that the oil pumped out of the well was none other than refined oil, probably diesel oil, an ingredient of the drilling mud used to lubricate the drill bit! The oil that was found had, according to them, actually been pumped down the well four months earlier when drilling began.

One might think that this disagreement over where the oil came from could have been resolved using analytic techniques such as gas chromatography and mass spectroscopy. Also surely anyone with a match and a sense of smell could tell the difference between fetid, often highly-flammable crude oil and refined diesel which does not easily ignite? But, as is often the case with golem science, things turned out to be much more complicated. When the analysis was completed it indicated the presence of certain chemical markers consistent with gilsonite, a drilling mud additive (there are other petrochemical components in drilling mud). This led some geochemists to conclude that no new oil had been found. But when the gas chromatography was completed, the recovered oil not only did not match that of refined diesel but, in addition, trace metals were found in higher concentrations than occur in diesel oil. What of the flame test? According to at least one report, the recovered oil was 'more easily ignitable than the diesel, and it had a different odor' (Cole, 1996, p. 746). Unfortunately no one anticipated this dispute and no sample of the drilling mud had been taken before it was poured down the hole. The geochemists were forced to turn some interpretative

somersaults in order to maintain their view that the oil came from drilling mud. They talked about possible chemical alterations to the diesel downhole, such as the enrichment of gilsonite, or even possible microbial activity which changed its constituents!

The data were ambiguous. The preferred conclusion depended upon which scenario seemed the more plausible: that there is naturally occurring oil in granite formations, or that drilling fluid undergoes some sort of chemical or biological metamorphosis downhole.

Gold, himself, was dissatisfied with this first experiment. Indeed he refers to it as a 'complete fiasco'. He redesigned the experiment substituting water-based drilling mud for oil-based drilling mud. A second well was sunk, Stenberg-1. Again methane and small, but significant, amounts of oil (12 tons of oily gunk or about 80 barrels of oil) were found. Gold hoped now, that if he had done nothing else, he had at least refuted the biogenic theory.

Immediately, however, supporters of the biological theory came up with a new explanation for the oil. The thin layer of sediment that covers the Siljan granite was claimed to be the source for the hydrocarbons. The suggestion was that the hydrocarbons had actually originated near the surface and had seeped downwards to form subterranean petroleum reservoirs:

> Paul Philp, a University of Oklahoma geochemist who analyzed examples of the 'black gunk' that Dala Djupgas extracted from the hole before pumping out the 80 barrels of oil, says that he could not distinguish between the samples from the hole and oil seeps found in shales near the surface in the Siljan area. The obvious explanation, says Philp, was that oil had simply migrated down to the granite from sedimentary rocks near the surface.
>
> *(Cole, 1996, p. 748)*

Cole goes on to remark:

> Gold, however, thinks that Philp has his facts upside-down, that the equally 'obvious explanation' for the similarity of samples is that oil and gas are seeping *up* to the surface.
>
> *(p. 748)*

Gold told Cole when asked about this issue:

> They would have it that the oil and gas we found down there was from the five feet of sediments on the top – had seeped all the way

> down six kilometers into the granite. I mean, such complete absurdity: you can imagine sitting there with five feet of soil and six kilometers underneath of dense granitic rock, and that methane produced up there has crawled all the way down in preference to water. Absolute nonsense! *(p. 748)*

Evidence was also found for biological activity, particularly in an oily magnetite putty that issued from the wells. Gold interpreted this sludge as indicating the presence of deep-dwelling bacteria that subsist on abiogenic petroleum and reduce iron into magnetite.

For the critics, the biological material had rather a different interpretation. It was further evidence that the well had been contaminated from the surface. Within their paradigm it was impossible for micro-organisms to survive at such a depth, therefore the only way they could have got there was from surface contamination, thereby proving that the oil must have seeped down from the surface. Whether contamination did or did not happen depended upon to which theories of oil and micro-organisms you subscribed. As one microbiologist commented:

> It may sound like double talk, but if the contamination problem is controlled and if you then get a sample up from deep underground under high temperature and high pressure and you find the organisms in that sample, then that's very good evidence that they exist deep underground. If the contamination problem is not controlled and you get the results that you're looking for – i.e. bacteria that grow under high temperature and high pressure, perhaps anaerobic bacteria, it doesn't necessarily mean that they're coming from deep underground. They could have come in with the fluids that you were pumping down into the borehole in order to obtain the sample and could result in the contamination. And there's always this little element of insecurity that we have, so that the final way that you use to check, if you can, is: does it make sense for these organisms that you isolate, knowing all the organisms that you possibly could isolate, does it make sense for *them* to be in these samples? And that's where you have to know a lot about the environment that you're sampling.
>
> *(Cole, 1996, p. 748–9)*

This is the 'experimenter's regress'. If you believe that microbiological activity exists at great depths then this is evidence that a competently performed experiment has been carried out. If you believe that microbiological activity is impossible or extremely unlikely then the evidence of biological activity is evidence for doubting the experiment. Experiment alone cannot settle the matter.

GIVE US A GUSHER

Gold's view of the crucial test is straightforward. He believes that he has accomplished what he set out to do – the biogenic theory has been shown to be false. From the point of view of the geologists, however, the matter is also settled; according to them Gold was given a fair chance but he failed to prove his case.

But perhaps even more telling for the critics is the commercial argument which underscores the scientific argument. In the end none of the niceties matter because Gold was not able to deliver a gusher. That, in the last analysis, would be irrefutable proof that his science was correct. And here Gold faces a dilemma. Drilling oil wells is a very expensive means of experimentation. In order to enlist the support of oil-barren Sweden, with its nuclear energy programme curtailed by environmental protests, Gold had to offer the expectation that they would find some commercially exploitable amounts of oil. As he told Cole:

> The Siljan structure is large by any standards. In areal extent, it is like Kuwait. So, if people ask me, 'how much are you expecting to find there', I answer, 'well, you could well imagine that you'll find another Kuwait'. So that was the reason for selecting it, and also, of course, it was easier to go to a wealthy country than to go to a poor country . . .
>
> *(Cole, 1996, p. 750)*

But no investor, however wealthy, wants to sink a well which only brings up oil of great scientific import, they also want commercial success and this Gold has so far failed to deliver.

What is interesting is that geologists sometimes support this subtle raising of the standards of proof by conceding the existence of some abiogenic hydrocarbons, but *not* commercial quantities. As William Travers, Cornell's resident petroleum geologist, puts it:

> There is methane that comes out of volcanoes, so you're not surprised that somebody discovers a bit of methane in a crystalline rock. It could have been primary methane and been there in the first place. But it's something else to say this can be produced in very large quantities, enough to supply Sweden with its energy requirements. A lot of gas would have to be extracted from those rocks. And I would say for Gold's theory to be valid one would have to find methane, at a bare-bones minimum – never mind oil – in huge quantities. Otherwise his theory's no good to us. It's nothing we didn't already know. What we don't believe, what we believe is not true, is that it can be found *in huge quantities* and extracted from those rocks *in huge quantities*. So that's the way the theory falls down. The trace amounts that have been discovered so far don't prove anything. They don't prove his theory, and they certainly don't relieve Sweden of any of its energy concerns.
>
> *(p. 751)*

By reminding everyone of Gold's promise that he could produce a gusher the critics have yet another way of dismissing the results of Stenberg-1. Gold, however, has a nice way of dealing with this criticism. He refers to the story of the chambermaid's baby. When the son of the household was forced to confess to being the father of the love child, he said: 'But it's such a *little* baby'! (Cole, unpublished). Also, if Gold had found a gusher we can speculate as to how the geological community might have responded to it. No doubt they would soon have come up with a convincing explanation as to why *this particular* gusher originated from biogenically produced oil.

Indeed, for one geologist it is the lack of commercial interest in what Gold had found in Sweden which is the most damning evidence. This geologist has pointed out that a 'show' (the term used by geologists to refer to the first signs of oil in a well) of 80 barrels is actually a very promising find for a wildcat. Usually such 'shows' would produce a great amount of interest and the rights to all available land nearby would quickly be bought up for more explorations. That this did not happen in the Siljan Ring, he felt raised questions about the validity of Gold's claims to have found some oil. That commercial standards of proof can run in a very different direction to scientific standards is indicated here. While, scientifically, 80 barrels of oil is no doubt impressive, from this viewpoint

Gold's mistake is to have found *too much* oil – the logic implies that if he had found less then the lack of immediate commercial interest would have made sense. That he found oil without producing a subsequent commercial interest implies something suspicious about this find. Indeed this selfsame geologist pointed to the tradition of pranksters in the oil industry – pranksters who might have turned their humour on Ivy-league professor Gold and his abiogenic theory by pouring the 80 barrels into the well themselves!

In any case, geologists, by playing up the connection between their theories and the commercial exploitation of oil, run the risk of drawing attention to the ways prospectors have actually found oil. Many oil prospectors describe their success as stemming more from art than from science. Indeed, parts of the world's oil supply have been found with scant regard for the prevailing geological wisdom. Big oil fields like Saudia Arabia, East Texas and West Texas were not found using standard geological methods. Oil prospectors cite instinct, as often as science, as the origin of their success. Frank Holmes, who promoted the first oil concessions in Saudi Arabia, 'in the face of the virtual unanimous verdict of the world's leading oil geologists that Arabia would be "oil dry", said his nose was his geologist' (Cole, 1996, p. 753). Wildcatters are known for their disregard of scientific and industry expertise. They recall John Archbold, the chief executive of Standard Oil, who in 1885 rashly promised to drink every gallon of oil produced west of the Mississippi and predicted the imminent exhaustion of the petroleum supply.

Gold claims that petroleum geologists often find oil fields by following fault lines from one producing well to another. Gold says that what prospectors are in fact doing is inadvertently tracing out petroleum generating structures located far deeper than the supposed source rocks:

> One can mention many examples where long lines flow from one geologic terrain into another and continue to be oil rich. And the oil prospecting people know that. They don't know why. But they mostly say 'well, we don't care why. It's of no interest to us why. We just know this a way of finding oil, and we just do it'.
>
> *(Cole, 1996, p. 754)*

Again, petroleum geologists dispute Gold here, citing independent scientific procedures as the source of new discoveries of oil fields and

criticizing Gold for introducing what they regard to be meaningless expressions like 'flow lines'. They think Gold has it wrong and that modern petroleum geology and the accompanying technology provides a much better way of finding oil than methods used back in the nineteenth century.

Gold has attracted a lot of criticism because Dala Djupas, the company that drilled the Swedish wells, has been bankrupted; Gold has been accused of partaking in a swindle, defrauding investors of money. Although Gold strongly rejects such claims, and most geologists Cole talked to in his recent study of the affair were careful to explain that the charges were only hearsay, there can be little doubt that the financial spin-offs have not helped Gold in his battle with the geologists. Gold is indignant about inferences his colleagues might draw:

> The idea that someone with a scientific career behind him would risk destroying it with a gross swindle of this kind is just so utterly absurd.
>
> *(Cole, 1998, p. 13)*

He also points out that financial self-interest can be cited against the geologists working for the oil industry:

> Do you suppose that the petroleum geologist who has been advising Exxon to drill for hundreds of millions of dollars for maybe thirty years, will go to his bosses at Exxon and say, 'I am sorry, sir, but I have been wrong all those years. We have been finding the petroleum, but if we had searched for it in another way, we would have found ten times as much?' . . . It is very unlikely that they will do that.
>
> *(Cole, unpublished)*

One of the most vituperative debates has concerned Gold's participation in a compendium produced by the United States Geological Survey (USGS) to promote the use of natural gas as a cleaner and potentially cheaper alternative to oil. David Howell, a USGS geologist, on hearing about Gold's theories about the origins of natural gas, invited him to submit an article to be included in the book. Howell soon found himself at the centre of a controversy as three of the eight members of his own editorial board resigned claiming that

publishing Gold's piece would damage the credibility of the Survey. The book was eventually published but outraged geologists circulated a letter of protest. In this they revived reports about financial misdealings in Sweden and called on the USGS to withdraw the book from libraries worldwide. Howell was shocked by the outcry:

> The most stupefying aspect to me was that university professors signed on with this letter saying that the book should be retracted. Burned! We were supposed to burn the book!
>
> *(Cole, 1998, p. 13)*

Howell also took with a grain of salt the allegations of wrong-doing – he felt it was a 'bit rich' coming from people so close to the petroleum industry:

> I thought, well what the hell has the petroleum industry been about for the last hundred years. You read the history of petroleum exploration, and it's filled with charlatans and guys with crazy ideas that are going out making big promotion and drilling and occasionally striking it rich. And then all the wells that were drilled that were known to be dry, purely for tax purposes. And I thought, this is part and parcel of the petroleum industry. Why are they having such a reaction?
>
> *(Cole, unpublished)*

Howell's own explanation for his colleagues' reaction is that Gold could dent the credibility of an industry bent on spending billions of dollars a year on oil exploration. Whether Howell is right or not, it is clear that issues of what counts as commercial credibility have become caught up with the more usual issues of scientific credibility. In short, Gold's non-biological theory and its assessment are intertwined with the politics and commerce of oil exploration. There is no neutral place where a 'pure' assessment of the validity of his claims can be made.

The remarkable thing about this case is that big, robust, expensive technological objects like oil wells have become subject to the niceties of technical disputes with which we are more familiar from research frontier science. The experimenter's regress applies to oil wells – this, of course, will be no surprise for petroleum geologists because drilling an oil well is to all intents and purposes just like running an experiment. This case, like the earlier chapter on the

Patriot missile, shows the other side of applied science and technology. The uncertainties and interpretative judgements which make up the craft of technology have seeped to the surface.

Whether Gold is right or not we do not know. Certainly most scientists think he is wrong. What is clear, however, is that deciding in a case like this, even when the odds are stacked so formidably against the scientific maverick, is rarely straightforward.

Lastly, in this debate we have seen that there is no neutral terrain where pure assessments of either side's case can be made. For the critics of Gold the experimenter's regress has been closed by appeal to commercial considerations – the fact that Gold has not been able to produce a gusher. But Gold in turn has questioned the actual part played by the standard biogenic theory in the practical world where oil prospectors operate. The burden of proof has been passed back and forth between the worlds of science and of technology. The residual uncertainties of golem science and technology are kept at bay by this ability to pass seamlessly between science and technology.

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Tidings of comfort and joy: Seven Wise Men and the science of economics

Shortly after the Second World War, an engineer from New Zealand, 'Bill' Phillips, working at the London School of Economics, built a model of the economy. The marvellous thing about this model was that it ran on water. Phillips's model was a set of tanks, valves, pumps, pipes, baffles and cisterns. If, say, the flow into some cistern increased while the cross section of the output remained the same, the water in the cistern would rise. The new level might increase the flow of water into another cistern, raising its level, or it might be enough to trigger a valve and restrict the flow somewhere else. The whole thing, which stood about seven feet high, weighed a good part of a ton, and was prone to leakage and corrosion, was meant to represent the flows of income around a national economy. Changes of levels were linked by indicators to scales which represented measures of economic performance such as price indices, stocks of money, or Gross National Product. It was even possible to link one of these gurgling monsters to another, thus representing the interaction of two national economies, or the interaction of one economy with the rest of the world. Phillips's hydraulic model of the economy has been restored recently and can be seen at the Science Museum in London.

Nowadays no one would dream of building a model of the economy that ran on water. Nowadays one would use a computer and the relationships would be represented by interacting mathematical equations. Using a computer and equations one can build the equivalent of many more pipes, tanks, and valves than one could ever construct with plumbing. This is what macroeconomic modellers do;