Palk Strait: Repairing Adam's Bridge with gypsum?

The first plan for the construction of a land connection between India and Sri Lanka dates back[1] to about 1876. Recently, Cathcart[2] has proposed the use of such a fixed connection to establish a series of wind turbines and vertical-axis hydro turbines, which would help meet future electricity demands in India and Sri Lanka. The shallow area of the Palk Strait, in places only about five fathoms deep, is underlain by thick Miocene Jaffna limestone[3], which also covers large parts of the Jaffna peninsula. A mostly submerged atoll barrier known as Adam's Bridge stretches from Danushkodi (India) to Thalaimannar (Sri Lanka). Although the land connection between India and Sri Lanka was interrupted by sea-level rise at the end of the last Ice Age, about 9–10 ka ago, the present tendency is towards sediment accretion, according to Ramasamy *et al.*[4]. It is even claimed that sediment accretion might in the future, in a few thousand years, reconnect the Vedaranniyam part of the Indian peninsula with the Jaffna peninsula.

Geotechnical risks of the constructions on shallow islands are erosion in general, and damage by cyclones or tsunamis funnelling into the Palk Strait. Such problems would be largely overcome if the bases of the constructions could be elevated. It is worthwhile, therefore, to see whether the islands can be raised, and their interconnection improved by applying a technology[5] that was first published in 1988. The following is a brief summary of the principle, and the results obtained thus far. Sulphuric acid reacts readily with limestone and water to give carbon dioxide and gypsum.

$$CaCO_3 \text{ (limestone; } 36.9 \text{ cm}^3\text{/mol)} + H_2O + H_2SO_4 \rightarrow CaSO_4.2H_2O \text{ (gypsum; } 74.7 \text{ cm}^3\text{/mol)} + CO_2.$$

The molar volume of the precipitated gypsum is twice that of the dissolved limestone. This means that the injection of sulphuric acid into subsurface limestone brings about a large expansion of the rock. This expansion can only be accommodated by surface uplift. This 'geochemical engineering' method[6] is considered a viable process to discard waste sulphuric acid and to raise the ground artificially for coastal protection. The reaction proceeds at all conceivable pressures, because even at moderate acid strength in the order of 20–25 wt%, the equilibrium CO_2 pressures amount to millions of bars. Thermodynamic data show that gypsum is stable below 50°C, down to a depth of approximately 1 km at a normal geothermal gradient. At higher temperatures and larger depth, gypsum transforms to the less voluminous anhydrite (45.9 cm^3/mol).

The process was developed with support from a grant of the Netherlands Technology Foundation[7]. Our experiments have shown that slow administration of sulphuric acid to porous limestone indeed causes a gradual but definite rock expansion, often accompanied by the formation of a network of small cracks ahead of the reaction front. However, fast injection of concentrated sulphuric acid leads to clogging of pore space with gypsum and a rapid decrease of the injection rate. Laboratory experiments with mixtures of acid injected at different concentrations and rates, into blocks, slabs and cores of various types of limestone, provide insight about successful injection strategies. After the laboratory experiments, some small-scale field experiments were carried out in an abandoned limestone quarry. Several thousand litres of sulphuric acid, or hydrochloric acid followed by sulphuric acid were injected into porous shallow subsurface limestones during approximately 6 h. Sensitive electronic tilt meters[8] placed in an array around the injection well clearly registered a modest surface uplift. Chemical analysis of the excavated and reacted rock shows a regular progressive limestone/gypsum transformation around the injection well.

The injection of sulphuric acid into subsurface limestone is a stable process. Initial variations of the permeability of the reservoir rock around the injection well diminish during carbonate dissolution and gypsum precipitation. A radial symmetric zone of expansion and uplift tends to form, and its evolution can be largely controlled by the rate of injection and composition of the injection fluid. The method is intended to protect the coast against an anticipated sea-level rise, or to raise land for the construction of air- and seaports. It has the advantage that it will not destroy or bury pre-existing structures, contrary to other methods. If industrial-waste sulphuric acids are used, which have a negative value, the method may be a cheap alternative to other technologies (see Box 1). If required, the strength of the industrial-waste acids can be adjusted by adding technical-grade sulphuric acid. It has been proved experimentally that heavy metals contained in the waste acids are immobilized at the reaction front between gypsum and limestone.

If we apply this technology to Adam's Bridge, it would mean that a number of deviated boreholes must be drilled in the Jaffna limestone. By drilling these holes close to the bottom of the limestone, which has a thickness of several hundred feet[3], an uplift of the seafloor centred over the borehole with a width of several hundred feet can be achieved. Theoretically, a limestone thickness of several hundred feet could be transformed into an uplift of several hundred feet, more than that required in the Palk Strait. It is proposed to leave a shell of unaffected limestone at the top in order to avoid any contact with the biosphere. This will also eliminate possible sulphate attack on any existing concrete constructions, although it should be kept in mind that sea water itself also has a fairly high sulphate content, so any concrete used should be sul-

Box 1

Is there enough waste acid to produce a significant effect? If we start with 1 m^3 of a waste acid with an acid strength of ~25 wt%, we can transform 0.120 m^3 of limestone into 0.240 m^3 of gypsum. This supposes that the liberated CO_2 occupies no volume, otherwise the expansion becomes more. We will start with a horizontal injection filter of length 500 m, and assume that a cross-section of 200 m, i.e. 100 m on either side of the filter will be affected, with its maximum uplift directly over the filter, and diminishing to 0 at a distance of 100 m. With 1 million m^3 of acid (a reasonable value for the annual acid production of a large industry), we can obtain a volume increase of 120,000 m^3. This translates into an average uplift of 1.2 m for the 100,000 m^2 affected, or, in the centre, in the order of 2.5 m.

phate-resistant. From each drill site, two holes can be drilled in opposite directions along the trend of Adam's Bridge. If the holes are deviated to almost horizontal, one can place filters of several hundred metres length in the borehole, and inject waste sulphuric acid into the limestone. The depth of injection is in the order of 100 m, so the injection pressures are no more than 10 to 20 bars, not enough to cause hydrofracturing. From the description of the Jaffna limestone it appears that the limestone is well jointed, which means that the acid will rapidly move into the limestone up to some distance from the points of injection. Intergranular diffusion plays no major role; transport of acid is mainly along small, existing or newly created fissures.

The uplift that is caused by the transformation of calcite into gypsum will result in a more or less continuous land barrier. It will, of course, be necessary to leave one or more gaps for shipping. Because the normal tidal currents will be interrupted over most of the distance between India and Sri Lanka, the current through the remaining gaps will be stronger, which is favourable for the emplacement of hydro turbines. Fears about a reduction of strength of the rock are probably unfounded. From laboratory experiments with confined limestones that cannot expand sideways, it appears that lateral expansion translates into an upward creep of the limestone, but the rock does not lose its cohesion. Gypsum rocks can form sound foundations. It is well known that several medieval towns in Germany are situated on mounds that rise from the plain, and are underlain by a gypsum caprock on top of rising salt diapirs.

When the method was published around 1990, it attracted a good amount of public attention. Some members of the public, however, were worried about possible environmental effects. There will be no direct effect on flora and fauna, as the rock transformation takes place well below the surface of the earth, separated from the biosphere by a layer of unreacted limestone. Indirectly, of course, if one changes a sea bottom into a land surface, there is an obvious effect. A second objection concerned the fate of heavy metals if polluted waste acids are used. We have shown experimentally that these are immobilized at the reaction front between gypsum and limestone, where the pH sharply rises. In fact, this makes the process an attractive way of neutralizing waste acids and removing their heavy-metal content. The third type of objection is related to the release of CO_2, which would contribute to the greenhouse effect. Although the argument seems logical at first sight, it is a fallacy. The chemical rule 'a strong acid dislodges a weak acid from its salts', holds also for the relation between sulphuric acid (strong) and carbonic acid (weak). Any strong acid at the earth's surface will prevent an equivalent amount of CO_2 from being removed from the atmosphere and sequestered in mineral form. In the subsurface, this same amount of acid will produce an equivalent amount of carbonic acid, but as long as some of that remains in the subsurface, for example, dissolved in formation waters, the process is favourable as regards the greenhouse gas balance.

India has many industries that produce waste sulphuric acids or low-grade technical grade sulphuric acid. An example of a large producer is the TiO_2 plant of Travancore Titanium Products near Trivandrum, Kerala. By shipping such waste acids to Adam's Bridge an environmental problem can be solved, while at the same time a contribution to a significant and economically valuable construction is made.

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Variety in DNA secondary structure

I wish to point out serious errors in the review article by Delmonte and Mann[1]. Without sufficient new ideas or any new experimental evidence, the article seeks to reopen a 20-year-old controversy that arose from the proposal by a couple of groups of a 'side-by-side' model of DNA structure[2,3]. The chief point of this model was that it sought to address the presumed topological and energetic problems that could arise when the Watson–Crick double helix, an interwound 'plectonaemic' structure was unwound during transcription and replication. The side-by-side model was a 'paranaemic' model with two strands and Watson–Crick base pairs, but without the interwinding. Several ingenious, but ultimately untenable suggestions were then made to explain the X-ray diffraction patterns, and the other experimental evidence available. However, the discovery of topoisomerases took the sting out of the topological objection to the plectonaemic double helix. And the more recent solution of the single crystal X-ray structure of the nucleosome core particle[4] showed nearly 150 base pairs of the DNA (i.e. about 15 complete turns), with a structure that is in all essential respects the same as the Watson–Crick model. This dealt a death blow to the idea that other forms of DNA, particularly double helical DNA, exist as anything other than local or transient structures.

The authors of the above review have stubbornly refused to accept this, going so far as to call into question some of the foundational principles of X-ray crystal-