GEOLOGY AS A CONTRIBUTOR TO NATIONAL ECONOMIES AND THEIR DEVELOPMENT

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Abstract

This paper examines the direct and indirect contribution to national economies attributable to the geosciences, principally as delivered by geological survey organisations. In particular, it looks at those sectors of the economy that depend to some degree or other on the provision of geological information, and tries to quantify the cost-benefits. This analysis is done partly through case studies of countries in different stages of economic development and, by comparing geoscience dependent outputs through time, adjusted for commodity price inflation, their impact on poverty alleviation is assessed.

Primary production of natural resources is one aspect of economic contribution. However there are other factors; these include cost-damage avoidance through better understanding and mitigation of natural hazards and of support for socio-economic stability in activities such as artisanal mining and minerals trading. Finally, there are trickle down economic indicators that result from skills and educational developments associated with inward investments. Set against this is the cost of environmental damage and social disorder that are often associated with resource exploitation.

The study brings together various published materials in an attempt to set a monetary value on the collection, management and dissemination of geoscience information.

Introduction

Since the beginning of the industrial revolution in the eighteenth century, and in isolated examples going back to pre-historic times, there has been a widely accepted association between geological knowledge and economic growth. The first geological map known to us, according to Harrell and Brown[1], was drawn on a papyrus to represent the Fawakhir gold mine. Iron was smelted from ores in Aswan and smelting was also carried out at Naukratis and Defna in the Delta region. The map was drawn about 1160 BC by the Scribe-of-the-Tomb Amennakhte, son of Ipuy. It was prepared for Ramesses IV's quarrying expedition to the Wadi Hammamat in the Eastern Desert, which exposes Precambrian rocks of the Arabian-Nubian Shield. The purpose of the expedition was to obtain blocks of bekhen-stone (metagraywacke sandstone) to be used for statues of the king.

The first modern style geological map was published by William Smith in England in 1815[2]. The purpose of the map was not simply to display the geology, it was to underpin decision making in where and what to mine, where to bury and sustain, where to build and tunnel. Geology had become and applied science.

During the nineteenth and twentieth centuries, it was widely recognised that national geological survey organisations, whose role was to collect, store and disseminate geoscience information, were an important contributor to wealth creation and quality of life, but little attempt was made to quantify those contributions in cost-benefit terms. A study[3] by the United States Geological Survey (USGS) in 1993 described examples, including that of a geological re-mapping of Loudoun County in Virginia for a road corridor and waste disposal site that had avoided costs estimated to be from $1.3m to $3.5m against the original plans. An engineering geology consultancy carried out by the British Geological Survey (BGS) in 1999 at a cost of £10k was calculated to have saved the pipeline company about £10m, a cost-benefit ratio of 1:100. But such cost evaluations are rarely made, partly because they are methodological difficulties and partly because publicly funded institutions have not been required, until recent times, to justify themselves in such terms.

It is more challenging to assign monetary value to natural hazard avoidance or mitigation that result from the application of geological knowledge. Whilst damage costs in terms of rebuilding, production losses and even the value of human life, can be calculated by governments or insurance companies, it is less easy to put a price on the value of protection that results from the careful monitoring and understanding of a volcano, or the avoidance of housing developments in areas at high risk of mudslides.

Economic value of geological information in the mining sector

Countries for which the primary industries of mining, quarrying and oil extraction form a significant part of their national product, are heavily reliant on geological infrastructure. This is clearly recognised by Australia and Canada, both of which maintain relatively well funded, world class geological survey organisations at both their federal and state / province levels. However, in many cases, mineral rich countries lack capacity in their geological survey organisations and depend on this being built through bilateral and multilateral aid programmes. There is competition for international inward investments, and less developed countries (LDCs) that have poor quality, old (non-digital) or unreliable geoscience information, principally geological maps, will not be attractive to investors. Such investors also look for political stability, a fair-but-firm mining code or petroleum law, reasonable infrastructure, including water supplies, absence of corruption and an available, educated and healthy work force. Thus LDCs need modern, digital and credible geoscience information and maps, and the technology and knowledge transfer suitable for the maintenance and sustainability of them.

It is relatively easy to calculate the direct costs of capacity building and maintenance in these cases, based on overall programme budgets provided by organisations such as the World Bank. Table 1 shows some recent examples of such programmes[4].

Country	Years	Amount (US$m)
Afghanistan	2006-2011	30
Argentina	1999-2001	23
Gabon	2005-2008	4.4
Madagascar	1999-2009	34
Mauritania	2003-2009	56
Mozambique	2001-2007	33
Nigeria	2004-2010	60
Papua New Guinea	2000-2006	11.5
Uganda	2003-2009	11.2
Zambia	1996-2008	156

Attempts to measure the benefits that result from such programmes are more difficult. In a comprehensive study[5] by Reedman *et al* published in 2000, the authors used indirect methods to value economic growth from mining activities that were probably based on earlier geological studies, albeit with a significant time delay. They found that, in general, the cost-benefit ratios varied in orders of magnitude from 1:100 to 1:1000 but this took place over at least a decadal time period. However, the difficulty remains in making a direct connection between the cost of the geological input and the value of the mining output, which may have occurred in the absence of the geological survey's input, on the basis of investor sponsored exploration work. Furthermore, the timescales are so extensive between inputs and outputs that world demand, changing commodity prices and political upheavals or stabilisations can mask meaningful comparisons.

We have compared these relationships in case studies for South Africa, Mozambique and the Democratic Republic of the Congo (DRC), formerly Zaire. All three countries are mineral rich; South Africa is a stable and developed nation with a long established advanced capacity in the geosciences through its geological survey, universities and many private sector firms. Mozambique suffered devastating post-colonial civil wars that destroyed much of its infrastructure and left it with an inadequate geosciences capacity but has in the last few years benefited from a significant World Bank (and others) development loan (table 1) to rebuild its geological capacity. The DRC has one of the greatest potential mineral resources in the world, but the sector is more-or-less dysfunctional because of war and political instability.

The basic economic indicators[6] of these three countries are shown in table 2.

Country	Area (km^2)	Population (2006, estimated)	GDP per capita (2006)	GDP (purchasing power parity) (2006)
Mozambique	801,590	20,905,585	$1500	$29.17bn
DRC	2,345,410	67,751,512	$700	$44.44bn
South Africa	1,219,912	43,997,828	$13,300	$587.5bn

South Africa's mineral industry produced sales revenues of US$ 7.4 billion in 2000, representing 6.5% of the country's GDP. Sales of primary mineral products accounted for nearly 35% of South Africa's total export revenue during 2000, with gold's contribution at 12 %. As a result of an increase in secondary and tertiary industries as well as a continuing decline in gold production, mining's contribution to South Africa's GDP has declined over the past 10 years (in 1991, mining's contribution to GDP was 8.4%), but has approximately retained its value in monetary terms after inflation. Thus, to a first degree of approximation, we see an established and stable economic activity producing a sectorial GDP per capita in the period 2000 to 2005 of about $800, which is dependent to some degree on a geological survey infrastructure cost[7] of $0.84 per capita per annum.

In the case of Mozambique, the mining sector accounted in 2000 for less than 2% of GDP, but provided a living, of sorts, for at least 50,000 workers in the informal artisanal sector. Part of the justification for the World Bank loan to support the geosciences capacity in the country was a planned growth of 15% per year in the mining sector between 2002 and 2005, by attracting investors partly as a result of the new maps and data[8]. In fact, growth has been better than planned, as shown by the annual percentage growth rates by mineral in table 3, which includes natural gas[9].

	2002	2003	2004
Coal	57.7	-15.6	-55.0
Bauxite	6.1	29.3	-23.9
Processed bentonite	128.3	18.0	-15.5
Selected bentonite	-23.0	-57.9	-32.5
Marble in plates	-34.8	2.5	33.6
Marble block-type	41.6	-0.2	36.5
Faceable garnet	0.0	-61.3	511.0
Gold	-23.2	271.6	-10.8
Aquamarine	-44.9	-69.4	132.1
Tourmalines	578.6	370.4	170.2
Tantalite	73.7	302.3	277.4
Beryl	6,687.5	44.2	-65.1
Sand	71.3	72.4	4.2
Limestone	78.4	3.6	18.2
Riolites	57.2	-9.6	5.8
Granites	1.2	-19.5	-3.4
Durmortiorite	-20.0	0.0	182.5
Natural gas	94.6	4.1	91,405.1
Total	**52.1**	**31.6**	**215.7**

Based on these data, the sectorial GDP per capita has risen from $30 in 2000 to over $60 in 2006, partly as a result of the World Bank (and others) investment in the sector at a cost equivalent of $0.32 per capita per annum.

Equivalent data for the DRC are more difficult to come by, but a recent report[10] by the Rights and Accountability in Development (RAID) organisation states that export earnings from mining have fallen from 25% of GDP in 1975 to about 2.5% of GDP in 2005, with GDP itself declining in real terms. Clearly, that fall cannot be attributed solely to the virtual absence of any sort of geological infrastructure, as political instability and other factors are primarily to blame, but it does show that the DRC remains unattractive to investors and operators for a variety of reasons.

Thus it seems that a cost (of geological infrastructure) to output (in the mining sector) ratio of 1:952 is found in South Africa's broadly stable and established system, with Mozambique experiencing an equivalent ratio of 1:188 by 2006. These results broadly match those of Reedman *et al* who used a very different approach to conclude that the cost-benefit ratios in their studies were between 1:100 and 1:1000 over a longer period. Further work is required to examine the ratio of cost to output in other countries and regions.

Economic value of geological information in the oil and gas sector

Traditionally, the oil and gas sector is less dependent on state sponsored geological information and is more willing to carry out its own exploration work. However, there remains a need for regional scale geological data and for a licensing and regulatory infrastructure to be in place before the major oil companies are attracted to invest heavily in an area. This requirement was recognised by the Government of Papua New Guinea and the World Bank which, in the 1990s, provided funding for development and knowledge transfer of the (then) Petroleum Division (PD) of the Ministry of Mines and Energy to attract and facilitate growth in the hydrocarbons sector. The various costs of these developments, at around $11.5m over a decade, contributed to a value growth in oil and gas exports from PNG between 1990 and

2000 of some $228m[11]. Some of this sum is attributable to commodity price increases, however oil remained at a fairly consistent price level during the 1990s, and so much of the value growth was the result of greater production. The cost-benefit ratio of the investment put into the PD to the increase in export earnings over the decade stands at about 1:20. However, the extent to which there was cause and effect, or simply the coincidence of two loosely related events, is a matter for some debate.

Economic value of geological understanding in geohazard mitigation

The principal natural hazards that affect the world are weather and its consequences (including floods, mudslides), earthquakes, volcanoes, tsunami, landslips and subsidence, natural contaminations such as arsenic in groundwater and radon, and extra-terrestrial impacts[12]. Those attributable to geological, as opposed to meteorological, causes have, over historical times, had greater impact (table 4) in terms of loss of life.

Year	Country	Deaths	Description
2004	Asia	260,000	tsunami
2003	Iran (Bam)	50,000	earthquake 6.3
1999	Venezuela	30,000	mudslides
1998	Armenia	100,000	earthquake 6.9
1998	California	11	earthquake 6.9
1998	Honduras / Nicaragua	10,000	hurricane (Mitch)
1976	China	750,000	earthquake 8.3
1970	Bangladesh	500,000	cyclone / floods
1970	Peru	18,000	landslide
1902	Martinique	30,000	volcano
1883	Indonesia	36,000	volcano / tsunami (Krakatoa)
1876	Japan	27,000	tsunami
1815	Indonesia	90,000	volcano
1815	Indonesia	90,000	volcano
1556	China	830,000	earthquake
1201	Egypt/Syria	1,100,000	earthquake

Table 4: selected natural disasters 1200 AD to present

Whilst no amount of geological knowledge can prevent hazards from occurring, its value comes in mitigating their impacts by advising on vulnerability reduction. This is well illustrated in table 4 by the almost identically sized earthquakes in Armenia and California, the former of which tragically caused some 100,000 deaths whereas the latter only 11. In California, the extensive understanding of the geology and physics of earthquakes has fed into planning controls, building regulations and civil defence which, because of sufficient wealth, are properly implemented. In Armenia, like so many other poor countries, the application of the inadequate geological knowledge is weak, leaving a highly vulnerable population.

Much has been written on the devastating tsunami that affected south east Asia on 26th December 2004. The damage cost has been estimated at $9.9 billion in addition to the loss of more than 260,000 lives. Loss prevention would have depended on far more than an effective early warning system; it would have required social programmes to move populations away from vulnerable areas and engineering solutions to provide some physical protection. Estimates for the installation and operation of an early warning system for the region are approximately $30m and it is pleasing to see that this initiative is underway, albeit some time after the main catastrophic events.

Volcano monitoring is a relatively cost effective way of mitigating damage, depending on the circumstances. In the British Overseas Territory island of Montserrat, in the Caribbean, the BGS has been involved in the monitoring of the Soufriere Hills Volcano almost since the start of its eruption in the mid 1990s. Montserrat is a small island, measuring 19kms by 11kms, whose economy was heavily dependent on sugar and tourism. Although nothing can be done to prevent the destruction of the former capital, Plymouth, and much of its surrounding countryside, careful monitoring of the volcano enables the authorities to adjust the extent of the exclusion zone according to levels of volcanic activity and risk, such that death and injury to the population is avoided. Furthermore, the presence of a competent volcano observatory instils confidence so that tourism, whilst reduced from previous levels, is still present to help sustain the island's economy.

The cost of monitoring is about £400,000 per year. The benefits are less easy to identify in financial terms as they include "losses avoided" – for example since formal monitoring began, there have been no deaths or serious injuries from volcanic activity, whereas before the current phase of monitoring, there were several fatalities. Putting a monetary value of this is impossible. However, if we assume that without the confidence generated by effective monitoring there would be little or no tourism, we estimate that the benefit to GDP is at least £6m per annum (although the economy as a whole still relies on some £20m per year of grant aid from the British Government)[13].

Insurance companies, of necessity, attribute monetary value to losses and damage. In recent years, UK insurers have calculated their losses on domestic property claims from ground movements to vary from £300m per year to over £800m per year. BGS now supplies geohazard susceptibility data to insurers at a ground resolution of tens of metres. These data feed directly into the premium calculations so that householders in higher risk areas are encouraged, by virtue of greater premiums, to take what mitigating action is possible, such as tree management. More importantly, fiscal pressures should in the future deter new development in areas of exceptional risk, where insurance premiums will become prohibitive.

Societal value

It is difficult to measure in financial terms the various contributions made by the geosciences to societal good. These range from the health care and productivity losses of sick people avoided through the supply of potable groundwater that results from hydrogeological studies, to the economic contributions made by workers who learn their basic skills in mining or petroleum before going on to reapply them in other sectors such as manufacturing or commerce.

In an attempt to understand this further in the UK context, Roger Tym and Partners were commissioned to address the twin issues of how does BGS contribute to the economy and what is the value of this contribution. Their report[14] describes the use of the OXERA value-added method as a measure of the organisation's contribution to the national economy based on the total value of all goods and services which use the BGS's products and services as an input. They found that "the total value added of national outputs to which BGS contributed for 2001 lies in the range of £34 billion to £61 billion, representing around 5% - 8% of total UK output" and excluded intangible benefits or aspects of well-being that have no monetary price, such as improved health and safety and ecological and environmental benefits. The annual cost of running BGS was, at that time, approximately £40m per year, which interestingly is about one thousandth of the value of the benefit, a ratio consistent with previous discussions.

Conclusions

This paper has looked at various ways that geological information and infrastructure, usually embodied in a geological survey organisation, can benefit the “healthier, wealthier and safer” society. In so doing, attempts are made to compare costs with gains in monetary terms. The difficulties of doing this have been recognised but, nevertheless, this and various other more comprehensive studies have all pointed to a cost to benefit ratio that is in the orders of magnitude 10^2 to 10^3.

What has not been looked at is the optimal level of expenditure on geological infrastructures. There is no suggestion that the cost-benefit ratios would be sustained if costs were increased; doubling the size and scope of a geological survey organisation is unlikely to generate a doubling of benefit for the economy, although halving it might have a greater effect in the opposite direction. This then raises the interesting, and unaddressed, question of what is the right size for expenditure under different conditions and circumstances. There is a great deal of scope for further research towards understanding a methodological approach to deciding optimal investment in geoscience information and infrastructure.

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[4] *Source: World Bank web site*

[5] *A J Reedman, A J, R C Calow and C Mortimer, 2000, Department For International Development, Technical Report WC/96/20, Overseas Geology Series, “Geological Surveys In Developing Countries: Strategies For Assistance”*

[6] *Source: CIA – The World Factbook*

[7] *Source: Annual Report of the South Africa Council for Geosciences, 2005*

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[9] *Source: Banco de Moçambique, Annual Report; MPF-05*

[10] *Rights and Accountability in Development, April 2007, “Demographic Republic of the Congo. Key Mining Contracts in Katanga : the economic argument for renegotiation” 21pp. London.*

[11] *Source – ADB web site*

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[13] *Sources: Department for International Development and BGS internal documents*

[14] *Roger Tym and Partners, 2003 “The Economic Value of the BGS” unpublished report*