Quantifying South Africa's carbon storage potential using geophysics

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Along with many other nations, South Africa faces the challenge of curbing carbon emissions, as coal-fired power plants generate 92% of the total electricity used. The result of this generation is the release into the atmosphere of 400 million tonnes of CO_2 annually, which contributes to the greenhouse gases that have a detrimental effect on global climate. Given the length of time needed to implement renewable energy sources, an alternative solution to significantly reduce greenhouse gas emissions is to capture the CO_2 produced by coal-fired power stations and store it in geological formations in the subsurface – a process broadly called carbon capture and storage. In order to successfully achieve this sequestration, a mechanism must exist to monitor the behaviour of the CO_2 injected into the earth.

Accordingly, in 2009 the South African government established the Centre for Carbon Capture and Storage,[1] a division of the South African National Energy Development Institute. The Centre is tasked with the research and technical development of carbon capture and storage. The establishment of the Centre was followed in 2010 by the publication of an atlas[1] which identifies and ranks potential CO_2 storage sites, mostly in Mesozoic basins along the coast (Outeniqua, Orange and Durban/Zululand basins), and to a lesser extent the Karoo Basin (Figure 1). The theoretical study that led to the production of the atlas was based largely on a literature review of all available boreholes and other geological information. What is needed is a more quantitative way of imaging potential storage sites, and I aim to address this need here.

The main challenge in carbon capture and storage is identifying those localities and geological settings within South Africa which have the greatest potential to store significant volumes of CO_2. The capture and storage of carbon is analogous to how oil and gas are naturally trapped in underground formations. Thus an ideal storage site must comprise a *porous and permeable medium* (e.g. sandstone) where CO_2 can be injected and stored, overlain by an impermeable cap rock (e.g. shale) that will retain (by dissolution or adsorption) the injected material and prevent it from moving or escaping into the atmosphere. Geological storage options for deep injection of CO_2 include depleted oil and gas formations, deep unmineable coal seams and deep saline formations - the last offering perhaps the most potential in the South African context.

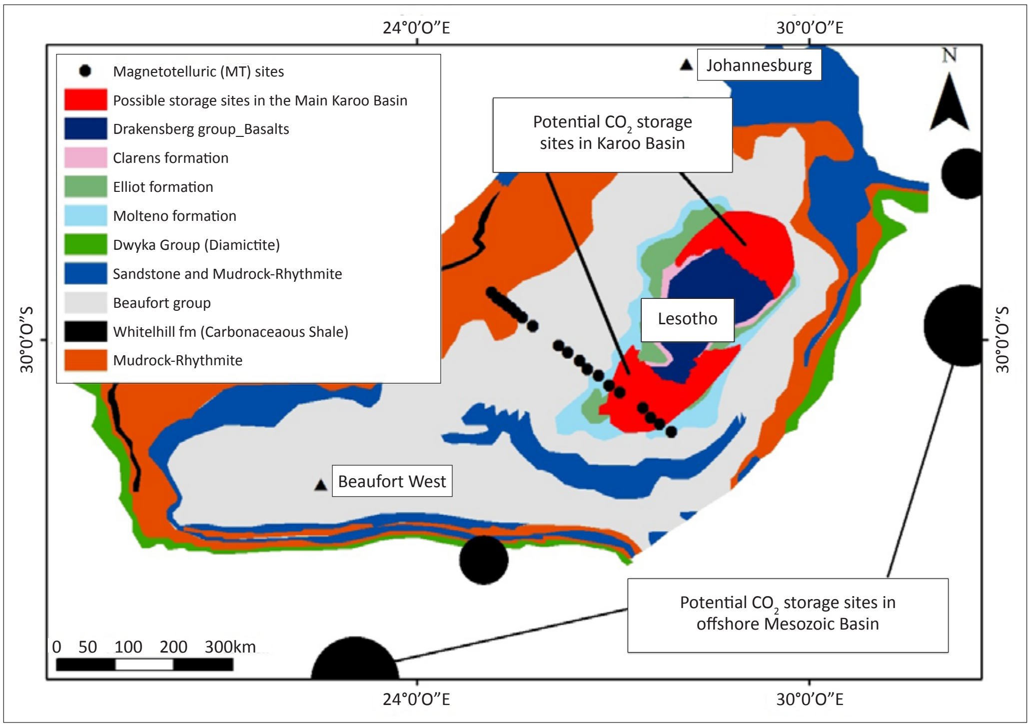

FIGURE 1: Map showing the distribution of potential onshore and offshore CO_2 storage sites and the locations of magnetotelluric stations in the Karoo Basin.

One of the potential storage sites identified[2] is in the Karoo Basin (Figure 1). Given the reported low permeability and porosity of the Ecca Group in the Karoo Basin, the potential for CO_2 storage in the region has been inferred as low[1]; more quantitative work needs to be undertaken to determine if this is the case. To this end, I am using a geophysical remote sensing method, magnetotellurics (MT), to provide quantitative estimates as to the storage potential of the Karoo Basin. The MT technique is a deep imaging geophysical technique whereby naturally occurring electric and magnetic fields (in the frequency range 1000 Hz – 0.001 Hz) are measured on the surface of the earth to determine the resistivity structure of the subsurface (from a few hundred metre to tens of kilometres). The resistivity of a rock formation is a function of four parameters, (1) the porosity of the rock that is occupied by a fluid; (2) the degree of interconnection of the fluid; (3) the resistivity of the host rock; and (4) the salinity of the groundwater. Thus, by knowing the resistivity of a geological formation we can, in principle, determine the rock properties (porosity and permeability) needed for reservoir characterisation using Archie's Law.[2] This principle is illustrated in Figure 2, which shows a porosity–resistivity–salinity nomogram that can be used to estimate porosity from bulk resistivity measurements. Thus, if one has temperature and salinity measurements (for example from boreholes) and resistivity from MT results to plot on a nomogram, connecting the points with a line of best fit would yield the resistivity of the pore fluid, which could in turn be used to estimate porosity.

In southern Africa we have collected over 750 MT sites as part of the highly successful Southern African Magnetotelluric Experiment,[3] in order to study the crustal and mantle structure of the region. Figure 2 shows an example of a resistivity response from one MT site in the Karoo Basin, which was derived from the processing of recorded electromagnetic responses. The two curves essentially represent apparent resistivity variations as a result of induced electrical current flow in directions parallel (transverse electric) and perpendicular (transverse magnetic) to the north-west to south-east profile. The abscissa represents the period in seconds (the inverse of frequency in Hz) which is a proxy for depth in kilometres. One can use the MT responses like these collected in the Karoo Basin to characterise one of the potential CO_2 storage sites shown in Figure 1. The MT sites are spaced at intervals of approximately 10 km – 15 km along a north-west to south-east profile. The acquisition of MT data is usually done along two-dimensional profiles, and at each site horizontal variations in electric and magnetic fields are recorded, using non-polarising electrodes for the former and magnetometers for the latter. For optimal resolution of geological formations such as in the Karoo Basin, much more detailed data is required. It is hoped that upon successful characterisation of onshore storage sites using MT, data acquisition will be extended to offshore basins.

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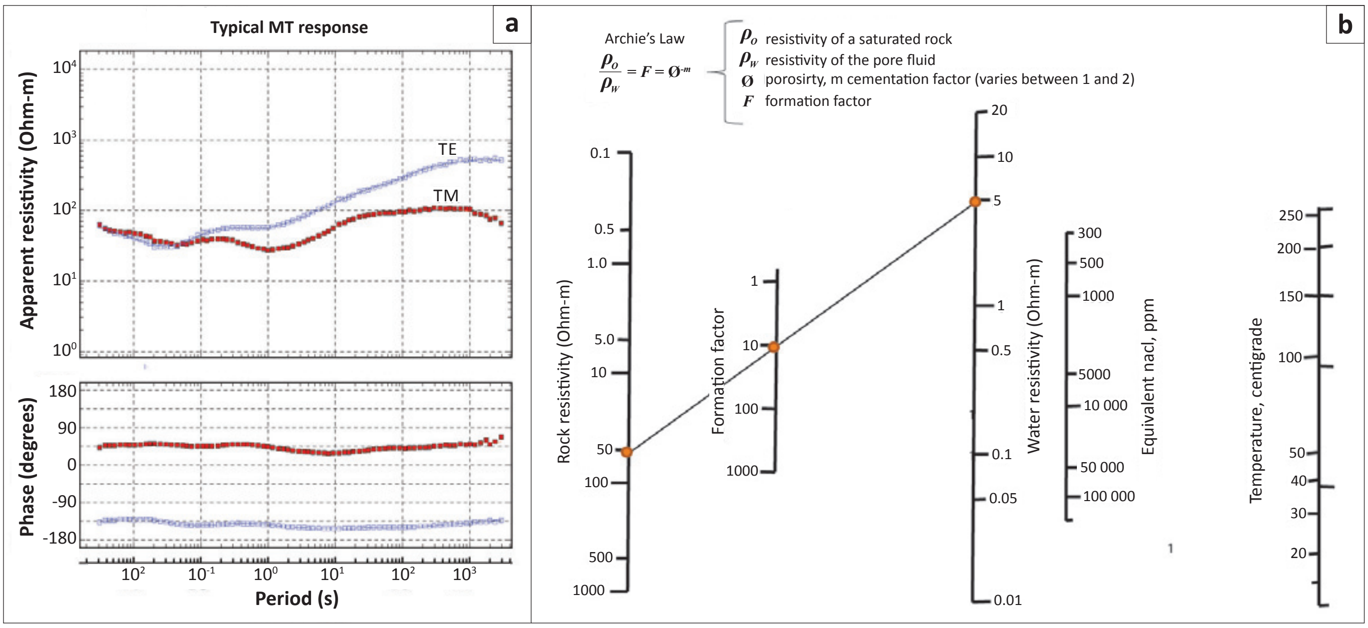

FIGURE 2: (a) An example of magnetotelluric (MT) data showing the transverse electric (TE) and transverse magnetic (TM) apparent resistivity and phase responses plotted against increasing period, the latter being a proxy for increasing depth. (b) The porosity–resistivity–salinity nomogram is used to estimate porosity percentage from bulk resistivity measurements.