I outline a personal view for a new metaphor for the geosciences; one that focuses attention on the services our accessible crust is capable of providing, now and into the future.

1. Children of the revolution

Scientists carry the purpose and enthusiasms that infused their training. That environment provided not only the questions, techniques and methods, but also the reason for their enterprise. Today's geoscientists were trained in the heady times of an extraordinary scientific revolution. Plate tectonics has completely reshaped our view of our planet. The tectonics of the 1950's already seems almost as foreign to today's students of plate tectonics as the Ptolmeic conception of the heaven's does to the modern astronomer! As children of the revolution there has been little need for the present generation of geoscientists to justify their work. That there was a completely new world order to discover was sufficient.

In the 40 years since the first great papers of plate tectonics were penned, geoscience has achieved a remarkable synthesis. While there is certainly more to be learned, much of the current effort is focussed on filling in the details. The grand conception is well enshrined. We know how the earth works, at least at the large scale, and are justly proud of our achievement. There are many remarkable testimonies to this success. One of the most compelling, I would argue, is in declining discovery rates of large mineral and energy resources. We have done such a good job in finding them, there maybe few more to be found!

If this is correct, then what now is the greater purpose for the geoscientist. What more do we have to offer? What is the appropriate metaphor to encourage young minds to this discipline? Below I outline what I see as a new emerging metaphor that focuses attention at a level of detail we have failed yet to grasp within the framework of plate tectonics.

Firstly, we should not loose sight of the role of geoscientists as custodians of one of the most important of all histories - the history of our planet! Human demands on basic earth resources (energy, water, metals, air) and human impacts on the functioning of the global system (ecosystems, climates, oceans) are unprecedented. We are acutely aware that our current activities are compromising the prospects of future generations, more than at any previous time in human history. In this context, sustainability is the key moral issue of our time. How are we to partition resources between the rich and the poor, between the present and the future and between the needs of human society and those of the environment? Moral traditions have always been informed by creation myths and the creation myths relevant to sustainability are the grand stories of our planet - stories such as the Snowball Earth, the Ediacaran explosion, the end of the dinosaurs, the Ice Ages, etc. Geoscientists have the special responsibility to tell these stories in a way that empowers all people to address the key issues of sustainability. We live on a planet of extraordinary beauty. Its intricate landforms, minerals, oceans, climates and ecosystems provide the threads connecting 4,500,000,000 years of planetary evolution. The story of our planet is a profoundly empowering story and has the potential to root all people to the well-being of the planet. Geoscientists provide a special perspective on this deeply spiritual story, and a special responsibility to tell it.

But there needs to be more. To address the issues at the heart of sustainability we need to know our resource inventories, and the capacity of the earth to continue to provide the services that underpin our wealth and health prospects. To make the choices that go to the heart of sustainability, we need a scientific capability that we are yet to achieve. Geoscientists now have the urgent responsibility to use their profound understanding of the functioning of the whole planet to define the distribution of resources and services provided by the earth, on which we have become, and will increasingly be, so dependent.

To achieve this we need a new and deeper understanding of the physical and chemical state of the accessible crust. Plate tectonics focussed our attention on how the crust came to be, rather than how it is. The distribution of temperature, stress, porosity, permeability, failure state etc. are only defined in most general terms in the construct of plate tectonics. There is an urgent need for geoscientists to turn their attention from the grand scale, to the small scale! To understand not only that rupture will occur at plate boundaries, but why it occurs in the way it does, so we can deliver better predictions to mitigate the devastating consequences of such rupture. To understand just how much CO_2 we can securely sequester into the crust, or ground water we can sustainably harvest, or geothermal energy we can utilize, or uranium we can extract to generate power into the future. To understand how the crust will service our needs into the future we need to understand the physical attributes of the crust in much greater level than we currently do. In this context a useful metaphor is provided by a new view of our crust as the provider of many crucial services that underpin the health and wealth of our societies, services that we risk jeopardizing at our peril.

2. The last Vicmanian

What were the last Vicmanians thinking confronted with the terrible reality that their land was drowning? The Vicmanians occupied Bass Strait during the first 30,000 years or so of human occupation of Australia. Prior to 10,000 years ago sea levels were lower than today, and Bass Straight was largely exposed. At the height of the last ice age 18,000 years ago sea levels were about 130 metres lower. Between 18,000 and 10,000 years ago the sea rose to present heights, progressively drowning Vicmania. Around 13,000 years ago, sea level was 65 lower and rising fast, at more than 2 meters per century, destroying the last land bridge and thus creating Bass Straight. The last Vicmanians were confronted with a fateful choice. Those that chose to stay south, the first true Tasmanians, forever separated from their northern cousins.

At 2 meters per century, the last land bridge must have been severed within the lifetime of one individual. Presumably there was a period when the bridge was shallow enough to bridge in low tide. But gradually the risks became too great. Presumably there were casualties; drownings, possibly family separations. Who knows, for all this is now 65 metres below sea level explaining just why we have such a fragmentary record of the first Australians. Their land is now largely submerged beneath the sea.

We now know that changes in sea level go had in hand with the amount of CO_2 in the atmosphere. Between 18,000 and 10,000 years ago, the concentration of CO_2 rose from about 200 to 280 ppm (parts per million) at the rate of about 1 ppm every 100 years. We know this because we can measure it in tiny air bubbles trapped in the great ice sheets of Antarctica and Greenland. These trapped bubbles tell a remarkable story of how our planet changes through time, and how it will change into the future. Over the last 50 years atmospheric CO_2 has been rising at rate of well over 100 ppm's per century. That is more than a 100 times as fast as when the last of Vicmanians witnessed the drowning of their land. What does it mean? To those of us versed in reading the record of our planet it can only mean one thing. We are committing to rising sea levels. Higher CO_2 levels go hand-in-hand with higher sea level - that is the undeniable message from the rocks!

Of course we might ask why haven't sea levels already risen significantly, since CO_2 levels are already way outside the range of the last few million years. The reason is that sea level rise is function of ice melting. As CO_2 increases, the atmosphere heats, and the ice begins to melt. We have increased CO_2 so rapidly that the atmosphere has not yet had time to heat the ice. But we know it is happening. Sea levels have begun to rise. Seas are getting warmer and expanding and the ice is beginning to melt. The last time in geological history we had so much CO_2 in the atmosphere there was very little ice on the planet and sea levels were very much higher than today, by between 60 and 70 meters higher. We can see this all around southern Australia. Five million years ago, the sea extended hundreds of kilometres inland across the Murray Basin as far as Kerang in northern Victoria. Australia was very different place, as it will inevitably become once again if atmospheric CO_2 levels remain at 400 ppm.

How long it will take we do not precisely know. But we do know that 13,000 years ago when the last Vicmanians disappeared and CO_2 was rising at just 1% present rates, sea levels were rising by at least at 2 meters per century. Our problem, or at least the problem for our children's children, is that we are committing to sea level rises of at least that magnitude. The history of our planet, the only history relevant to this story, tells us so. It is written in the rocks.

Most of the evidence of the first 30,000 years of occupation of this continent is now submerged beneath the sea, along now drowned former coastal fringes. Just like the first Australians, much of the evidence of our occupation will also be submerged. The CO_2 we are putting into the atmosphere is committing the melting of the ice. Once the ice is gone sea levels will be 60-70 metres higher. Almost all the great cities of today will be submerged. At 2 metres per century we are talking just 3,000 years hence. The story of the rocks tells us so!

Climate change is the biggest issue of our time. Climate projections point to a range of possibilities. There is uncertainty; modeling is just an informed estimate of potential realities. Many are alarmed. Others cannot see the changes happening, and are skeptical. Where is the sea level rise, they ask? We who read the story of the rocks know there is nothing new in such change, and future change is expected as part of an ongoing cycle. We attribute that change to different things and still have important lessons to learn. But we should not be confused. Our planet has never had so much CO_2 in the atmosphere with so much ice on the land. The most important history, the history of our planet, tells us something must give. Just when, we do not precisely know, but the record of Earth's past is unambiguous. Our seas must rise and we will have to adapt.

The cause of our problem is simple. We have taken for granted a fundamental service provided by our natural environment. For 10,000 years we have lived with an equable climate, at least when compared with the preceding 100,000 years. We have assumed the climate is a given. We have built our cities along the sea front, as hubs based around our ocean going transport systems. We did not understand that sea levels could change. Now we know sea levels have changed in the past and surely will in the future. We also now understand that change is imminent because the CO_2 we are injecting into the atmosphere is compromising this most basic of natural services. Because of the CO_2, our climate can no longer balance the amount of ice and water on the planet required to maintain stable sea levels at these historical levels.

Understanding the services that the natural environment provides is essential to adaptation to future change, and this includes the services provided by our crust. Within the story of the last Vicmanian is a powerful lesson that tells of own predicament and should align geoscientists with a new sense of purpose. We need urgently to understand the capacity of the services provided by our natural environment; services on which we have become so crucially dependent, including those provided by the rocks beneath.

3. Crustal services

The concept of ecosystem services is well established in environmental science, relating to those resources and processes provided by natural ecosystems for which there is human demand. By explicitly branding such services we are able to attribute value to them, focus on threats and limitations, and evaluate trade-offs between immediate and long-term human needs for such services. To help inform decision-makers, economic value is increasingly associated with many ecosystem services.

The service metaphor is easily extended beyond ecosystems to the entire natural world. Another key service provider is our crust. Our crust provides the platform for all human activity. It provides energy and mineral resources for present and future activity. It provides systems that route and store crucial groundwater reserves. Increasingly it is seen as a secure container for our hazardous waste. Viewing the crust in terms of the services it provides for human societies provides a new narrative for the geosciences in much the same way that ecological services has for the environmental sciences. It focuses attention on the emerging need to define just how much our crust can provide and thereby inform crucial infrastructure choices concerned, for example, with provisioning secure, affordable and sustainable energy supply into the future.

With increasing numbers of people aspiring to the standard of living that the people of the west enjoy, we can no longer assure many crustal services that we now take for granted. We have long been aware of issues relating to soils and groundwater, but declining rates of discovery for most mineral and energy resources suggest we are moving into a new regime of finite resource. Simultaneously, demands for new crustal services are being driven by emerging technologies, the necessity to secure hazardous waste, and population pressures that increase our exposure to natural hazards.

Several examples highlight how the crustal service metaphor changes the current problem conception in the geosciences.

Metal services. Massive copper deposits suggest there is little concern for future reserves. However, asking what service we demand of copper poses a different problem set. In Western societies like Australia, each individual is serviced by ~200 kg of copper (in inner city Sydney it is closer to 600 kg). To service the world's population at these levels would require we extract all the copper in the crust and put it to use. In the future, much greater levels of recycling will be needed to secure copper services at present Western levels.

At its' current service level, the uranium reserve is about 90 years. However if we want uranium to replace the service that coal currently provides, that lifetime drops by a factor of 5, and the reserve of readily discoverable uranium may be as low as 6 years. At such service levels, very significant new discovery will be needed to secure the reserve over the lifetime of the infrastructure needed to put it into service. Viewing the resource in terms of the service we want it to provide informs the value option for the associated infrastructure choices we must now contemplate.

New services. The energy futures debate is sparking exciting development in materials science. In the photovoltaics space, new compounds based on indium and gallium offer cheaper production costs. Lithium is a key prospect in battery technology. Platinum is a superb catalyst for fuel cells. In all cases there are serious concerns that the crustal resource will prevent such technologies from scaling to useful levels. Some emerging technologies will prove stillborn because they cannot be adequately serviced by resources.

We have long understood that the crust's natural porosity is precious where it holds natural gas and oil, but we now demand that these tiny 'holes in the crust' deliver a new sort of service by securing our waste. There is a desperate urgency in evaluating how much and how securely such precious holes can serve this crucial new function.

A stable platform. The crust provides the platform for all human activities. We understand the platform is not without risk. Earthquakes, volcanoes and floods all impact on how we understand this most basic of services. Population pressures demand we occupy ever more vulnerable sites, especially in Asia, increasing our exposure to crustal instability. We also know that large engineering projects change the nature of that risk. For example, as sea-levels rise with climate change, we should anticipate that the loading of our crust around the coastal fringe will result in 'induced' earthquakes and increased vulnerability to floods for existing and future infrastructure.

To better understand the capacity of, and threats to, existing and emerging crustal services we need a new level of understanding of our accessible crust. We need this understanding especially as we contemplate rebuilding our energy production infrastructure to insure that it best serves the needs of both present and future generations. The level of understanding we need will be comparable to that of the 'oil patch', but will need to extend across the entire accessible crustal domain. To achieve this, we will need new, much cheaper ways of imaging and modeling the accessible crust and its resource inventories, all with an unprecedented level of detail. This is the emerging challenge for the geosciences.