Coal consumption: an anthropogenic legacy measured by marine organisms

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ABSTRACT

Throughout human history, from the dawn of man to present day, burning thermal coal has been an essential part of life. Thermal coal was burned as an easy source for heat by early humans, and later on, as an easy source for power. With the First Industrial Revolution in Great Britain from 1760-1840, steam engines, powered by coal, saw an explosion of production and usage. Across the pond, in the U.S.A., as well as in the rest of continental Europe and in Japan, the Second Industrial Revolution from 1840-1914, saw further increases in the burning of coal in the manufacturing of goods. Although other fossil fuels saw increases as an energy source, coal remained king as the top used energy source.

Burning of coal – thermal and metallurgical – leads to the release of various chemicals and compounds including heavy metals such as selenium (Se). Se is required by many organisms to sustain life, however, in large doses Se is toxic. Tracking and monitoring the burning of thermal coal during the Industrial Revolutions are of vital importance to the well-being of both terrestrial and marine life forms. In brachiopods from 1926-1960 Se molar levels approximately doubled from 5.7 mmol to 11.9 mmol within the calcite shell. This steady increase in Se emissions was mitigated in the 1960s by the installation of thermal coal scrubbers. Their use helped reduce harmful emissions from the combustion of coal, while reducing soot and heavy metals being released into the atmosphere. This technological step is witnessed by a rapid decline in Se levels within brachiopod shells, which saw a decrease of approximately 9 mmol from the 1960s to the 1980s. With coal scrubbers successful in reducing emissions, this reduction in Se is to be expected. However, not every thermal coal-burning power plant incorporates the appropriate scrubbers. This increase in consumption to present day is mirrored in the Se levels within brachiopod shells, which have also seen an increase to approximately 9.2 mmol of Se. This clearly demonstrates the effectiveness of scrubbers in removing harmful contaminants such as Se and the great potential of marine invertebrates in tracing the industrial progression and its transgressions.

Our research has the potential to be an important tracer of thermal coal combustion, introducing a new proxy for the tracking of anthropogenic activity.

Background

- Globally, temperatures are shown to be increasing since pre-industrial times (Figure 2).
- Global atmospheric and oceanic temperatures are both observed to be increasing.
- Global atmospheric CO_2 levels and CO_2 emissions are observed to be increasing, accelerating at the 1950's.
- The level of CO_2 emissions from coal burning been increasing as well, despite the introduction of cleaner fossil fuels. CO_2 emitted from coal combustion would be depleted of the Carbon-13 isotope due to the Suess Effect.
- Coal emissions also include heavy metals (e.g. selenium)

Methods

-Brachiopods (Figure 1) from various localities around the world, were sampled.
- Using a combination of the Z-score and the Tukey's Fences method, the data was cleaned of outliers which can bias the results.
- Data was analysed for trends and correlated to historical events such as the introduction of the Clean Air Act and various remediation technologies.

Figure 1: A brachiopod, *Calloria inconspicua*, used in this study

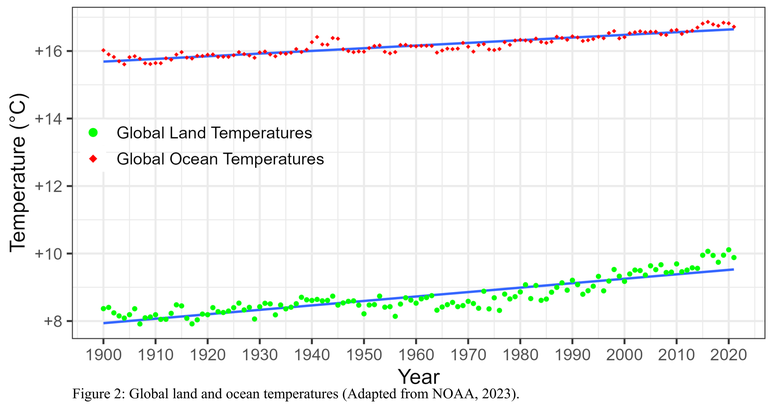

Figure 2: Global land and ocean temperatures (Adapted from NOAA, 2023).

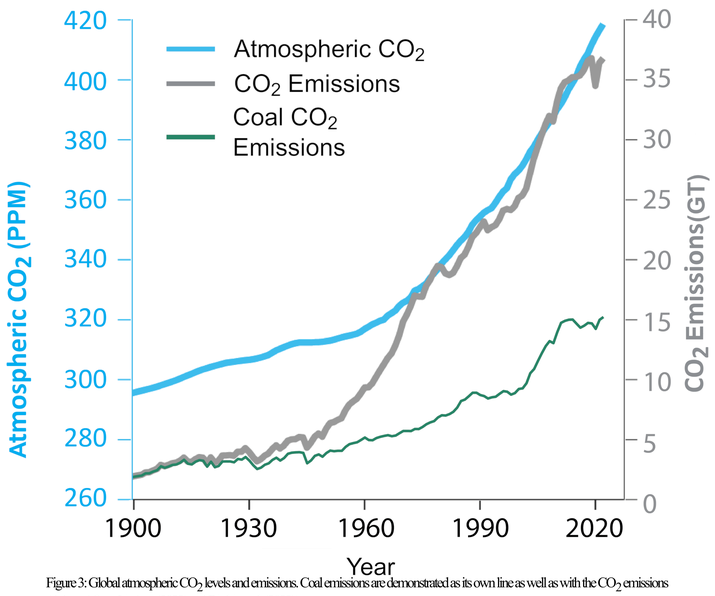

Figure 3: Global atmospheric CO_2 levels and emissions. Coal emissions are demonstrated as its own line as well as with the CO_2 emissions (Adapted from Lindsey (2023) and Ritchie et al. (2023)).

Results

- Selenium levels show trends in line with the introduction of various remediation technologies and legislature designed to lessen the environmental impact of burning coal (Figure 4).
- By examining the $\delta^{13}C$ levels it can be seen that there is indeed a decrease in the Carbon-12 Isotope, verifying that the brachiopods are detecting the effects of fossil fuel combustion.

Table 1: A summary of the results. SE_{pre} ranges from 1926 to 1960, Se_{mid} from 1960 to 1980, Se_{post} from 2009 to 2022. $\delta^{13}C$ levels ranges from 1900 to 2014

Criteria	R^2	Δ
$\delta^{13}C$	0.17	-0.48 ‰ pdb
Se_{pre}	---	+6.0 mmol
Se_{mid}	0.74	-8.5 mmol
Se_{post}	0.06	+0.83 mmol

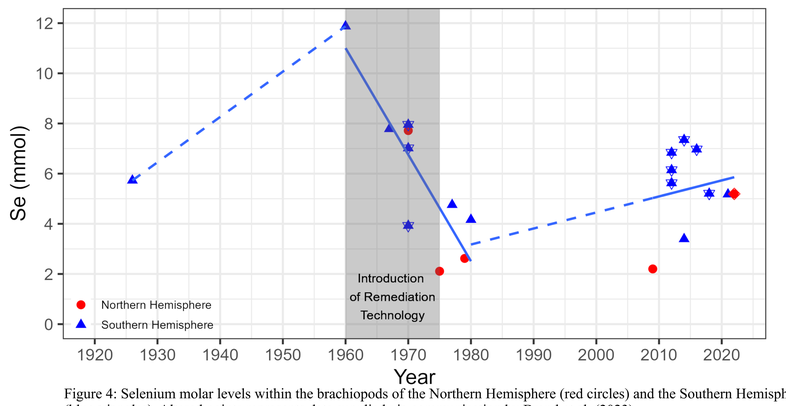

Figure 4: Selenium molar levels within the brachiopods of the Northern Hemisphere (red circles) and the Southern Hemisphere (blue triangles). Altered points represents data supplied via communication by Brand et al. (2023).

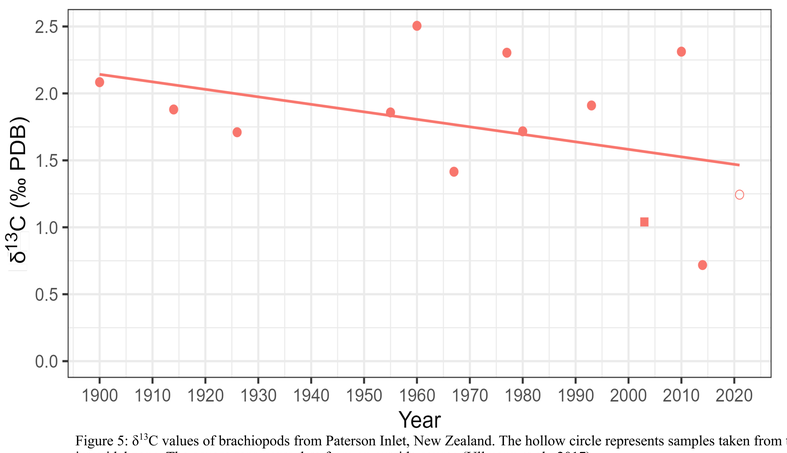

Figure 5: $\delta^{13}C$ values of brachiopods from Paterson Inlet, New Zealand. The hollow circle represents samples taken from the an intertidal zone, The square represents data from an outside source (Ullmann et al., 2017).

Summary

- Selenium levels in brachiopod shells show value as a tracer for coal consumption.
- Coal is a large source of CO_2 (Figure 3).
- Global levels of atmospheric CO_2 are increasing.
- CO_2 from fossil fuels are depleted in the Carbon-13 isotope which decreases the atmospheric $\delta^{13}C$ values.
- $\delta^{13}C$ levels within brachiopods have been decreasing (Figure 5), indicating atmospheric CO_2 is mixing into the oceans and is being detected by brachiopods.
- Selenium levels align with the $\delta^{13}C$ levels within the brachiopod shells.
- Brachiopods may hold the key to tracking anthropogenic coal burning.

References

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