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# THE APPLICATIONS OF PALAEONTOLOGY IN THE CONTEMPORARY WORLD: A CASE STUDY OF FOSSIL SEA SHELLS

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### ABSTRACT

This study highlights the many applications of modern palaeontology, through the lens of an examination of fossil sea shells (brachiopods) from Oriel Brook in eastern Ireland. This fauna thrived across the globe some 446 million years ago, during the Late Katian stage of the Upper Ordovician Period. Several brachiopods were identified and, for the first time, four previously undocumented genera from Oriel Brook were discovered. A number of these findings, including the discovery of *Foliomena* sp., confirmed with certainty that these brachiopods belong to the *Foliomena* fauna. A faunal list was then compiled and statistically compared to other *Foliomena* faunas found globally, using the specialist software package PAST [PAlaeontological STatistics]. From this statistical manipulation, these brachiopods were placed in a distinct geographical region on the Ordovician globe and at a specific relative water depth. It is from such detailed analyses that changing continental configurations and the evolution of ecosystems over deep time are deduced. This is only one of the uses of modern-day palaeontology, which can answer various questions applicable to an ever-changing contemporary world. Notably, observations of changes in biodiversity and climate over time gives us context of the impact of our actions on the world today. This study demonstrates that fossils can be used as vitally important ‘tools’ which tell a story, allowing us to open a window into the deep past which is key in understanding our future.

### INTRODUCTION

*Palaeontology* is defined as the study of fossil plants and animals which helps establish ancient environments and conditions of life throughout Earth history (adapted from Allaby, 2013). Yet, this has only been made possible through the many quantitative approaches which use fossils as tools to tell a story that modern palaeontology has adopted in recent years, (Benton & Harper, 2009; Wyse Jackson, 2012). This is seen in the many applications Palaeontology has today, from allowing us to better understand the past geographies and climates experienced on our planet (Wyse Jackson, 2012), to tracking the origins and evolution of life, through the observation of changes to biodiversity over time. The study of fossils has even served as a great asset to industry, particularly required in the timing of past tectonic and geological events to the high-precision dating of rocks, in some cases to the nearest ten to one hundred thousand years. This continues to play a significant role in the search for important economic deposits and natural resources (Benton & Harper, 2009).

In this present study, a quantitative analysis is undertaken on a group of fossil-shelled organisms called brachiopods, first described from a formation known as Oriel Brook in eastern Ireland, and later considered to share similarities to what is known as the *Foliomena* fauna. This fauna resided globally, occupying the deeper part of the continental shelf for some 15 million years during the Ordovician period before disappearing during the end Ordovician mass extinction event (Zhan et al. 2014).

Through further examination of the fossil collections and subsequent statistical analysis, this study will investigate the following questions:

- Faunal affinity - Do these brachiopods belong to the *Foliomena* fauna?
- Palaeogeographical setting – In what region of the Ordovician globe did these brachiopods live?
- Relative-water depth - What depth on the continental shelf did these brachiopods inhabit?

### The Late Ordovician World

The Ordovician was a geological period in the Earth’s history, between 485.4 ±1.9 million years ago and 443.8 ±1.5 million years ago. This present study focuses particularly on the late Katian stage of the Upper Ordovician, approximately 446 million years ago (Cohen et al. 2013; updated by the International Commission on Stratigraphy). The Ordovician witnessed one of the most vital periods of change seen in marine organisms in the planet’s history. During this period, known as the Great Ordovician Biodiversification Event (GOBE), the diversity of marine animals increased threefold in just 25 million years (Webby et al. 2004; Harper 2006). The greatest diversity peak of the GOBE occurred in the late Katian (Webby, 2000; Webby et al., 2004) (Fig. 1).

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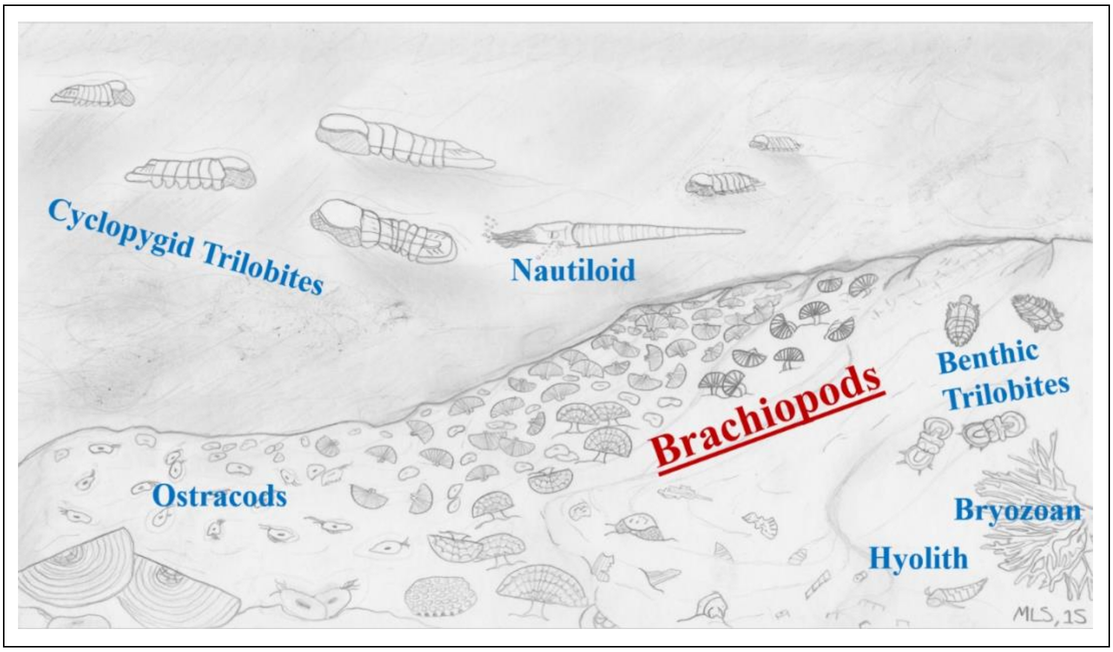


**Figure 1: Sketch of an imaginary scene of Oriel Brook during the late Katian (not to scale), featuring the ‘Foliomena Community’ (Harper & Mitchell 1982; Renbin et al. 2010).**

At this time, the position of the Earth’s continents was very different from the one observed today. Servais et al. (2009) stated that the Ordovician saw the maximum separation of the continents (for a map of the Ordivician globe, see Fig. 5). Some of today’s continents had come together to form large landmasses, whereas others were scattered throughout the oceans, along with microcontinents and even smaller pieces of the earth’s crust called terranes, which record their own unique geological histories.

The Irish Grangegeeth terrane, which features the Oriel Brook brachiopod fauna, will be the prime focus of this study. Its positioning on the Ordovician globe and its relative water depth spectrum have proven historically controversial (Harper & Mitchell 1982; Owen et al. 1992). Previous brachiopod studies have suggested a North American origin within the vicinity of the ancient Iapetus Ocean; however, this was later called into question by Cocks et al. (1997) and Van Staal et al. (1998), who argued that the terrane was in fact a fragment from the fringes of the southern supercontinent, Gondwana. Tripp et al. (1989) also stated that trilobites found at Oriel Brook are like those that belong to widespread fauna which also inhabited the Chinese region. More recent evidence by Zhan & Jin (2005), show that Oriel Brook and the Chinese region also present similar brachiopods, strengthening their apparent connection. Through the study of Cyclopygids (pelagic (swimming) trilobites that also feature in this study, and that are known for their large eyes), Owen and Romano (2011) later discovered that Oriel Brook was a low latitude shelf or slope facing an ocean (Fig. 1).

Their data, along with further statistical analysis of their more recent collecting, in conjunction with a statistical comparison with other *Foliomena* faunas from around the world, will be used to deduce the true palaeogeographical affinity of the Oriel Brook fauna, by placing it closer to either the Chinese or the Iapetus region; moreover, these data will be used to indicate the likely position on the deep shelf of the Oriel Brook brachiopods.

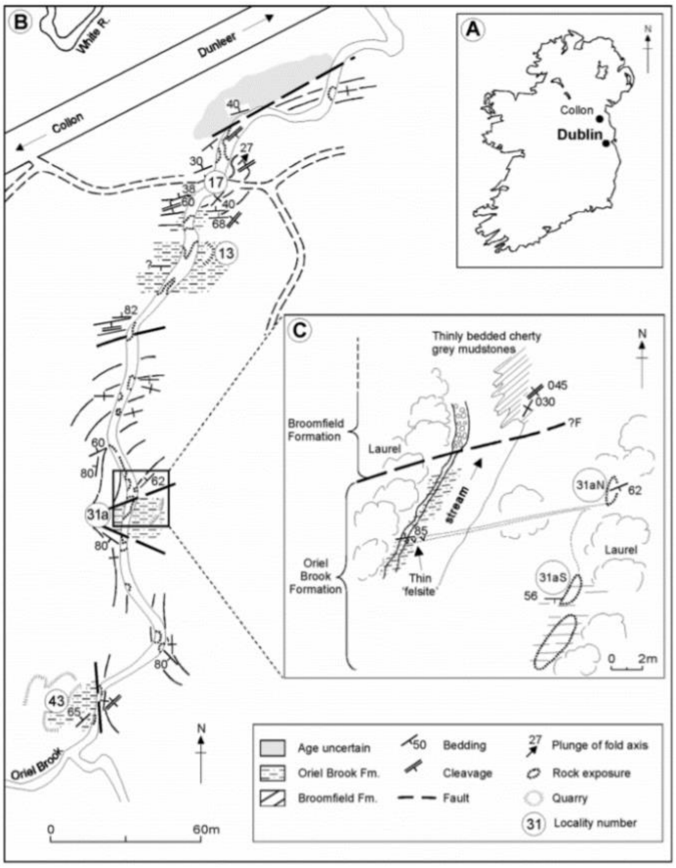


***Figure 2: Map of Oriel Brook (Owen & Romano 2011).*** ***(a)*** *Collon village highlighted on a map of Ireland.* ***(b)*** *Geological map of Oriel Brook section, 2.75km from Collon (modified from Romano, 1980, figure 9).* ***(c)*** *Field sketch of Oriel Brook fossil localities.*

## METHODOLOGY

The fossil material collected from Oriel Brook and examined in this study came from three separate collections which sampled from the following numbered site localities: 31aN, 31aS, 43, 13 and 17 (Owen & Romano, 2011) (Fig 2). The material collected from all these localities was examined in detail for brachiopod fossils; the field number of each sample and the number of rock fragments present were documented in decreasing order of size. Each piece of rock was then thoroughly examined using a binocular microscope and a brief description was made. The process of identifying a fossil brachiopod as belonging to a particular genus began with comparing any specimens to photographs of previously identified brachiopods from Oriel Brook itself, which originated from Harper & Mitchell (1982). Subsequently, each specimen was compared to higher quality photographs from Sheehan (1973) and to images of brachiopods from Girvan (Scotland) found in the three-part monograph by D.A.T. Harper (1984; 1989; 2006); additionally, other *Foliomena* fauna papers were used (Zhan & Jin 2005; Zhan et al. 2014; Neuman 1994; Liang et al. 2014; Candela 2011; Villas et al. 2002; Cocks & Rong 1988; Rong et al. 1999). In total, 384 individual rock fragments (with sizes ranging from over 15cm to less than 5mm) where examined. The brachiopod data collected from the Oriel Brook specimen examination, such as the different genera present and their abundance, were then used for further analysis.

### Data Compilation and Analysis

Microsoft Excel 2010 was used to compile the data collected from the Oriel Brook samples. First, the abundance data of each genus of brachiopod found in each locality was compiled into a spreadsheet format. This allowed the data to be expressed as pie charts, showing the relative percentages of each genus per locality. Excel was also used to record the presence and absence data of particular brachiopods from Oriel Brook, which were then included with the known presence and absence data of other late Katian *Foliomena* faunas. This data matrix was then copied into PAST [PAlaeontological STatistics] (http://folk.uio.no/ohammer/past/) which has become a standard tool for analyses in Palaeontology. This computer package was used to provide a large number of quantitative analyses.

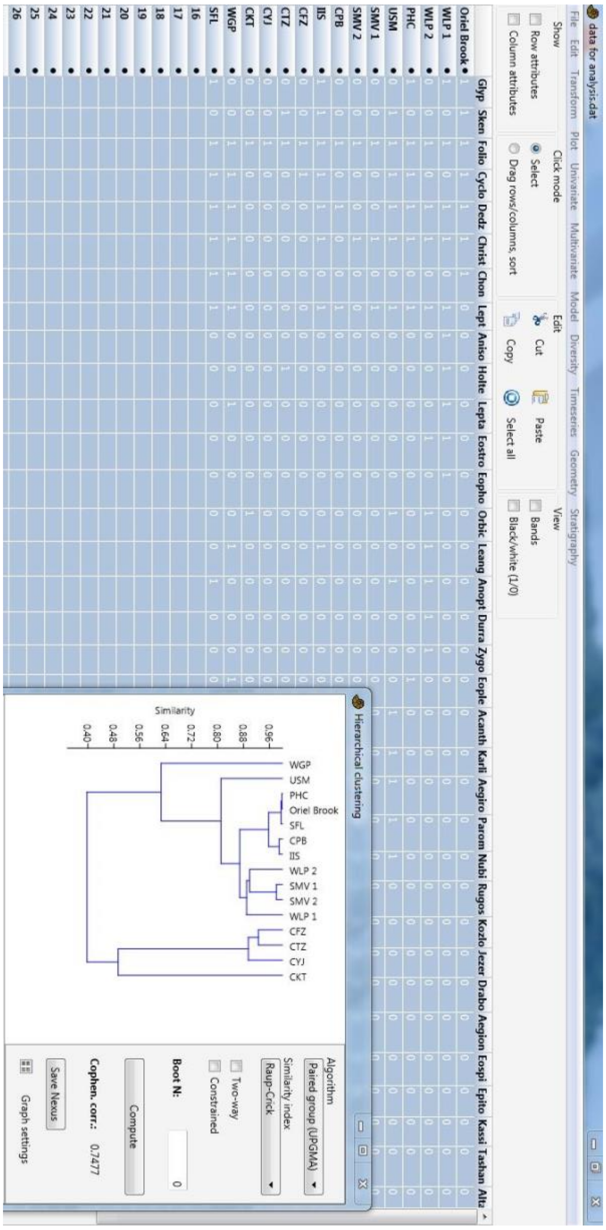
Two quantitative techniques were chosen from PAST and performed in this study. One of the techniques used is a cluster analysis, which compares pairs of samples and groups them in terms of greatest similarity. This is then displayed on a tree-like diagram called a dendrogram (Fig. 3). Seriation is another statistical method, which compares samples by "shuffling" samples and genera in the data matrix, to get the best possible fit of presences along a diagonal. If ordering along the diagonal is strong, then the sequence order of localities may indicate their original sequence along an environmental gradient, such as increasing water depth (Dean *et al.*, 2010).

## RESULTS

### Faunal List

The composition of the Oriel Brook brachiopod fauna analysed in this study (Fig. 4) includes:

- *Glyptorthis* sp.
- *Cyclospira* sp.
- *Chonetoidea* sp.
- *Skenidioides* sp.
- *Dedzetina* sp.
- Lingulate brachiopod
- *Foliomena sp.*
- *Christiania sp.*



Algorithm: Paired group (UPGMA)

Similarity index: Raup-Crick

☐ Two-way

☐ Constrained

Boot N: 0

Cophen. corr.: 0.7477

***Figure 3: Screen-print of analysis using PAST , featuring dendrogram (see main text).***

Of the brachiopods featuring in the faunal list, four genera are previously undocumented from Oriel Brook: *Foliomena*, *Dedzetina*, *Cyclospira*, and a lingulate brachiopod. Various studies have stated that the fundamental members of the *Foliomena* fauna include the brachiopods *Christiania*, *Dedzetina* and *Cyclospira* (Harper, 1979, 1980; Williams and Wright, 1981; Cocks and Rong, 1988; Rong et al., 1999). Along with *Foliomena* itself, all four of these brachiopods have been documented at Oriel Brook, suggesting these Irish fossils can be attributed to the *Foliomena* fauna known worldwide.

The results show that *Chonetoidea* is by far the most abundant genus in the Oriel Brook material investigated, making up more than half of all brachiopod specimens found (Fig. 4). Oriel Brook samples taken from 31aN were dominated by fossil brachiopods, particularly *Chonetoidea*, whereas samples from 31aS were rich in fossil ostracods and contained all the *Foliomena* specimens. Zhan & Jin (2005) identified a greater relative water depth by the occurrence of the brachiopods

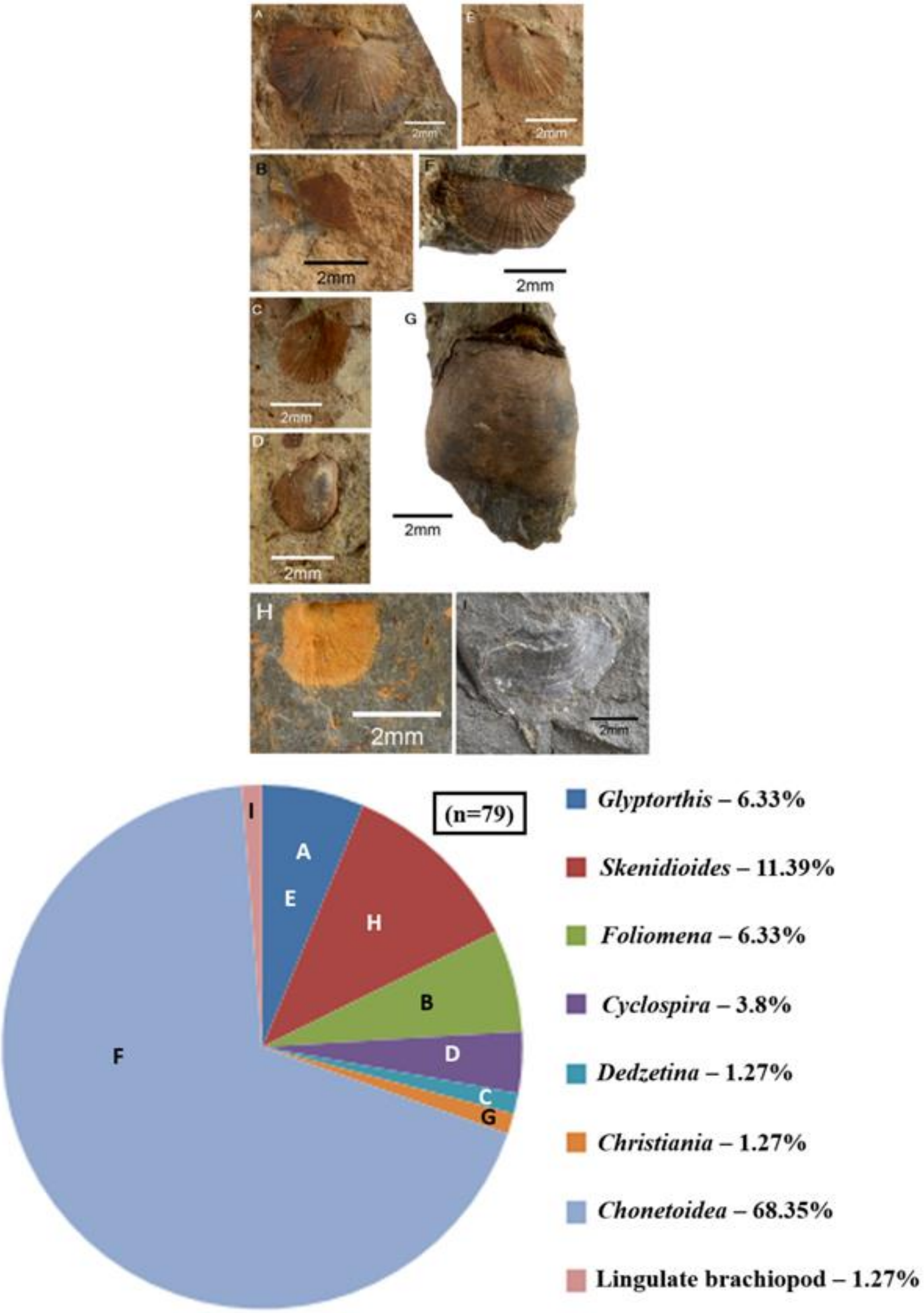


**Figure 4: Brachiopod genera identified from Oriel Brook.**

**Upper panel: photographs (credit: Les Hill)**

**(A)** Glyptorthis from 31aN29. **(B)** Foliomena from 31aS17. **(C)** Dedzetina from 31aN21. **(D)** Cyclospira from 31aN27. **(E)** Glyptorthis from 31aN27. **(F)** Chonetoidea from 31aS22. **(G)** Christiania from 43S. **(H)** Skenidioides from 31aN20. **(I)** Lingulate brachiopod from 31aS22.

**Lower panel: pie chart (n = total number of specimens)**

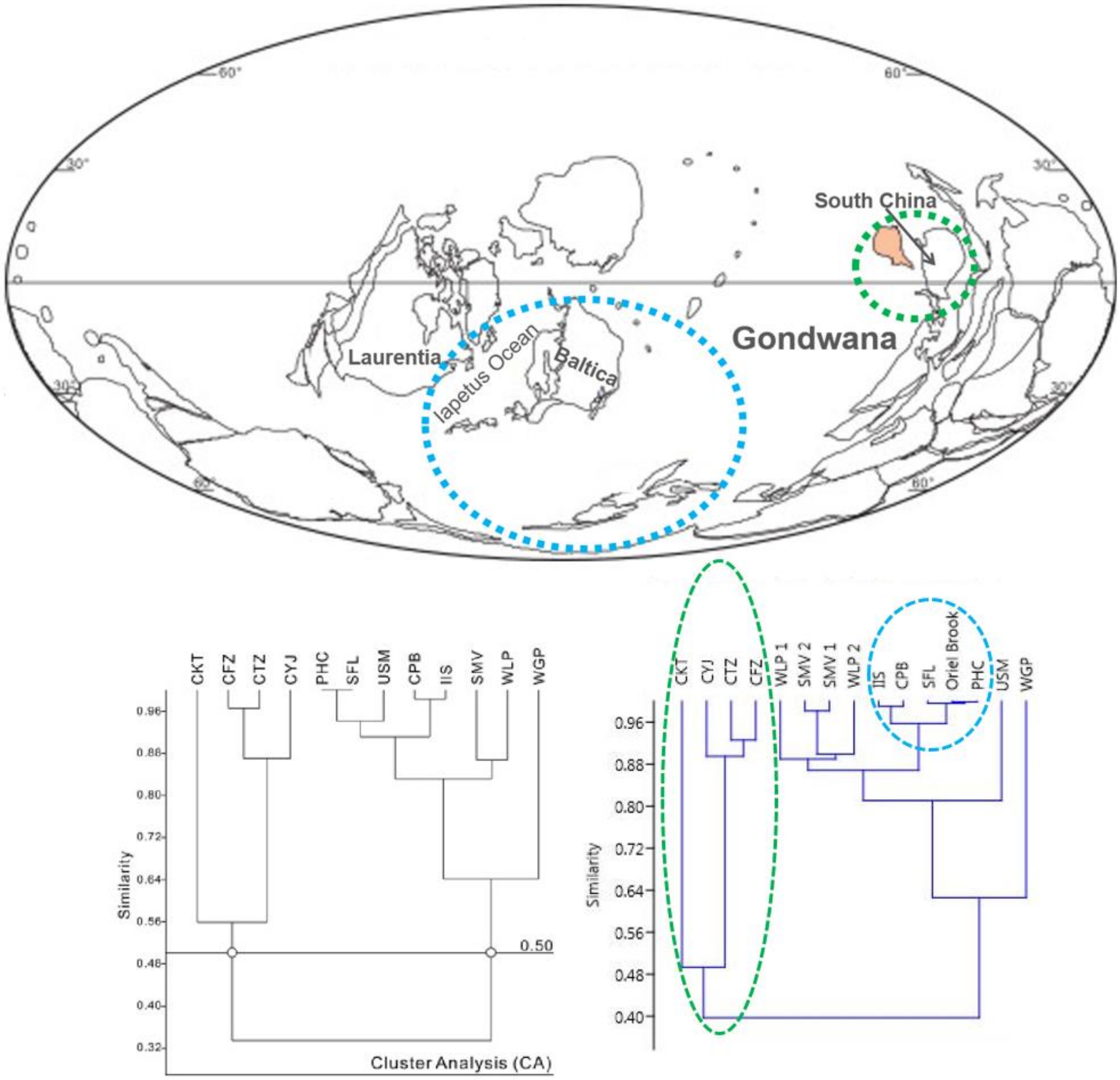


***Figure 5: Cluster analysis of samples and their geographical locations: comparison between the analysis in the present study (right) and the analysis of Zhan et al. (2014) (left).***

*Iapetus branch is matched with Iapetus region (blue) and Chinese branch is matched with Chinese region (green) on the Ordovician globe. Ancient continents highlighted include; Laurentia: (North America); Baltica: (Scandinavia) and the Gondwanan supercontinent (majority of present southern hemisphere landmasses); [Globe adapted from base map of Boucot et al., (2009), modified in Zhan et al. (2014)].*

*Locality abbreviations of Foliomena associations or communities in Zhan & Jin (2005) (in which faunal data was accessed to create the new cluster analysis) with their counterpart abbreviations used in Zhan et al. (2014) and the present study; Afon Penfhos, Llyn Peninsula, North Wales [AP=WLP 1], Crugan Lane, Llyn Peninsula, North Wales [CL=WLP 2], Holy Cross Mountain, Southeast Poland [HC=PHC], Northeastern Maine, USA [MN=USM], Västergötland, Sweden (Jonstorp Formation) [SW=SMV 1], Västergötland, Sweden (Ulunda Mudstone) [VG=SMV 2], Prague, Czech Republic [PR=CPB], Sardinia, Italy [SD=IIS], Fengzu, Zhejiang Province, eastern China [FZ=CFZ], Tanshi, Zhejiang Province, eastern China [TS=CTZ], Xiazhen, Jiangxi Province, eastern China [XZ=CYJ] Northeastern Tarim, Xinjiang, northwest China[CKT], Garth District, Powys, central Wales [WGP], Scania, Sweden [SC=SFL].*

*Cyclospira*, *Dedzetina* and *Foliomena,* thus placing them on the outer continental shelf, comparable to a so-called Benthic Assemblage (BA) 5-6 setting (Owen & Bruton, 2012). On the other hand, studies on *Chonetoidea* show it inhabited high-energy, nutrient-rich environments of a shallower relative water depth (BA3-4), equivalent to a depth >60 metres (Rong et al., 1994, 1999; Owen & Bruton, 2012). This places *Chonetoidea* on the mid-shelf, instead of the deeper water outer shelf like the other brachiopods and so many other *Foliomena* faunas. Here, relative water depth might explain the subtle differences between 31aN and 31aS. However, as 31aN had a significantly larger sample size compared to the other site localities, further sampling might be required to obtain a clearer census of different genera per locality.

## DISCUSSION

### Palaeogeographical Setting and Relative Water Depth

In this study, a cluster analysis including the data collected from Oriel Brook was created and compared to the original cluster analysis undertaken by Zhan et al. (2014) on late Katian *Foliomena* faunas. The aim was to observe whether any similarities or differences existed between the two studies, and to deduce what region on the Ordovician globe the Oriel Brook brachiopods inhabited. Upon comparison of the two studies, a very similar pattern emerged, where the *Foliomena* fauna is concentrated in two separate geographical groups, which are here referred to as the 'Iapetus' and 'Chinese' regions (Fig. 5). Both analyses place the Chinese faunas on a separate branch from the rest of the world. Crucially, this study does not place the Oriel Brook fauna on this specific branch, suggesting it was greatly dissimilar to the Chinese brachiopod faunas, and therefore not in close geographic proximality to the Chinese region during the Ordovician.

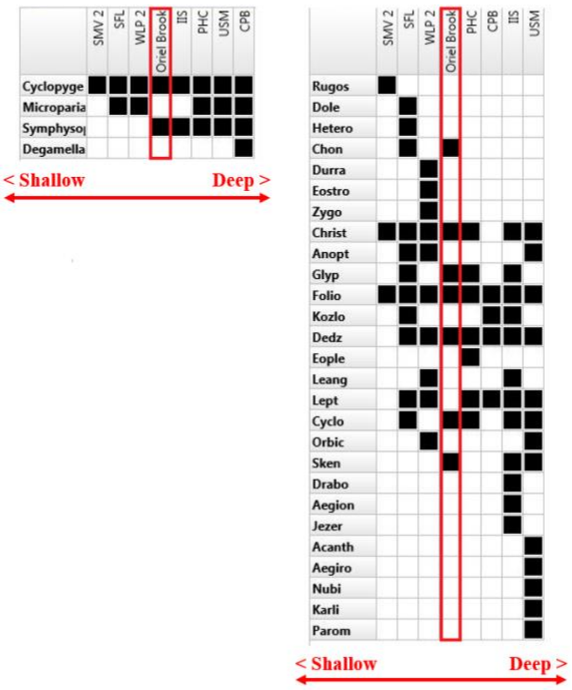
While the results of Zhan et al. (2014) show that the most similar faunas were the Polish and Swedish (from Baltica) and the Sardinian and Czech (from Gondwana), this study clustered Oriel Brook closer to the fauna from Sweden and paired it directly with the fauna from Poland. This shows that Oriel Brook is nearly identical to these faunas. Oriel Brook was also clustered close to the Czech and Sardinian samples, suggesting they too share very similar faunas. This is supported by both Sardinian and Swedish faunas sharing several brachiopods with the Oriel Brook assemblage (Zhan & Jin, 2005). Oriel Brook's strong correlation to these faunas can be explained by shelly faunas becoming more uniform across all ancient continents, particularly in the Iapetus region, as the ancient ocean was beginning to close (Owen & Romano, 2011). By the late Ordovician, the majority of *Foliomena* faunas, which include the above mentioned localities and Oriel Brook, would be found living in the region of the Iapetus Ocean, as seen on palaeogeographic reconstructions of the globe during the late Katian (Cocks and Fortey, 1988) (Fig. 5). As the Oriel Brook fauna shows the greatest similarity to these faunas, this study places it with confidence in the Iapetus region.

A major difference between the present cluster analysis and that of Zhan et al. (2014) is that the latter grouped the north-eastern Maine (USA) fauna between the Polish/Southern Swedish and Czech/Sardinian faunas. Their close affinity suggested these landmasses must have been close to each other during the Ordovician (Scotese and McKerrow, 1990; Owen and Crame, 2002; Boucot et al., 2009). However, in the present cluster analysis, the introduction of Oriel Brook has caused north-eastern Maine to be displaced from these faunas and to branch off to the side (Fig. 5). Although the Maine fauna features many of the same brachiopods as Oriel Brook, its assemblage is dominated by the brachiopod *Foliomena* (Neuman, 1994). However, comparison of both localities' trilobites highlights Maine's difference from Oriel Brook, as a particularly dominant trilobite is non-existent in Maine (Owen & Bruton, 2012). Owen & Bruton (2012) further use this comparison to account for palaeoenvironmental differences existing between the two localities, which could explain why Maine was displaced in this present study. While the *Foliomena* fauna from Maine is described as to have inhabited colder waters of the deep (BA5-6) range (Neuman, 1994; Owen & Bruton, 2012), Zhan et al. (2014) states that the characteristic Welsh, Polish, Swedish and Czech *Foliomena* faunas share this same relative water depth range. Therefore, the variation between the two studies must originate not from palaeogeography, but from differences in palaeotemperature between the localities. Overall, this shows that the environment inhabited by the Oriel Brook fauna was more similar to the one typical of the Polish/Southern Swedish and Czech/Sardinian faunas, rather than that of the north-eastern Maine fauna.

Data collected in this study were also used to find out at what depth on the continental shelf the Oriel Brook brachiopods lived. A cluster analysis by Zhan & Jin (2005) was recreated in the present study, which also included most of the late Katian data investigated by Zhen et al. (2014). This produced a dendrogram, which was then compared with the original by Zhan & Jin (2005). Both cluster analyses grouped together the Polish, the Southern Swedish, and the Sardinian faunas (which are close to Oriel Brook) in a cluster which reflects the general deeper end of the relative water depth spectrum (Zhan & Jin 2005). The Sardinian *Foliomena* fauna was shown to have lived at a relative water depth of ≥200 metres (BA3-4 range), suggesting that the Oriel Brook brachiopod fauna might have lived at a similar depth; Polish and Southern Swedish faunas were placed at the deeper BA5-6 range in the relative water depth spectrum (Sheehan, 1973; Harper, 1980, 1984; Cock and Rong, 1988; Rong et al., 1994, 1999; Villas et al. 2002).

To determine with more precision the depth inhabited by the Oriel Brook fauna between these two depth ranges, a comparison was carried out with an associated number of cyclopygid trilobites, which are routinely found alongside *Foliomena* faunas (Renbin et al. 2010; Owen & Bruton, 2012) (Fig. 6). Two seriations were performed, one involving cyclopygids and the other involving the brachiopods. The cyclopygid seriation fixed the sequence of localities along a depth gradient, which was based on a much bigger data matrix published by Owen & Bruton (2012). The brachiopod seriation was not fixed, allowing the sequence of localities to be changed during the seriation. Cyclopygid trilobites lived throughout the water column and therefore their fossil abundance increases the greater the relative water depth (Price and Magor, 1984; Zhou et al., 1994, 2001, 2003, 2007; Owen & Bruton, 2012). Both seriations show an increasing water depth trend from left to right; similarly, the number of cyclopygids also increased from left to right. The seriations more accurately place Oriel Brook around the middle of the diagonal, which would position it in the mid-deep relative water depth spectrum. This is equivalent to the shallower end of the cyclopygid depth range of 200-700 metres (Fortey and Owens, 1987).

Therefore, the seriation, along with the other lines of evidence, points towards the Oriel Brook fauna inhabiting a relative mid-deep depth on the relative water depth spectrum, corresponding to at least 200 metres. This lies towards the shallower end of the benthic assemblage (BA4-6) which is the characteristic relative water depth range for many known *Foliomena* faunas (Harper, 1979; Rong et al., 1999; Renbin et al. 2010; Owen & Bruton, 2012).



| | SMV 2 | SFL | WLP 2 | Oriel Brook | IIS | PHC | USM | CPB |
|---|---|---|---|---|---|---|---|---|
| Cyclopyge | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Microparia | | ■ | ■ | | | ■ | ■ | ■ |
| Symphyso | | | | ■ | ■ | ■ | ■ | ■ |
| Degamella | | | | | | | | ■ |

| | SMV 2 | SFL | WLP 2 | Oriel Brook | PHC | CPB | IIS | USM |
|---|---|---|---|---|---|---|---|---|
| Rugos | ■ | | | | | | | |
| Dole | | ■ | | | | | | |
| Hetero | | ■ | | | | | | |
| Chon | | ■ | | ■ | | | | |
| Durra | | | ■ | | | | | |
| Eostro | | | ■ | | | | | |
| Zygo | | | ■ | | | | | |
| Christ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ |
| Anopt | | ■ | ■ | | | | | ■ |
| Glyp | | ■ | | ■ | ■ | | ■ | |
| Folio | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
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| Dedz | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
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| Leang | | | ■ | | | | ■ | |
| Lept | | ■ | ■ | | ■ | ■ | ■ | ■ |
| Cyclo | | ■ | | ■ | ■ | | ■ | ■ |
| Orbic | | | ■ | | | | | ■ |
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| Drabo | | | | | | | ■ | |
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| Acanth | | | | | | | | ■ |
| Aegiro | | | | | | | | ■ |
| Nubi | | | | | | | | ■ |
| Karli | | | | | | | | ■ |
| Parom | | | | | | | | ■ |

***Figure 6: Comparison between trilobite (left) and brachiopod (right) seriations.***
*Red box: Oriel Brook. Locality abbreviations as per Fig. 5.*

## CONCLUSION

According to the findings in this study, the Oriel Brook brachiopod fauna is confirmed to belong to the *Foliomena* fauna through the discovery of four new genera: a lingulate brachiopod, *Dedzetina*, *Cyclospira*, and the first ever documented *Foliomena* at this site. This confirms the earlier suspicions of Harper (1979; 1980) who could only suggest that the fossil material resembled that of a '*Foliomena* fauna'.

In relation to their palaeogeographical setting, the cluster analysis shows that the Oriel Brook fauna was most comparable to the Polish and Southern Swedish faunas; a strong correlation was observed with other localities that lay within the Iapetus region, rather than with the Chinese region. This further supports a geochemical analysis (McConnell et al. 2010) showing that the Grangegeeth terrane had strong ties to Laurentia. This, along with the new palaeontological evidence of this study, allows the Grangegeeth terrane of eastern Ireland to be now positioned with certainty within the Iapetus region of the Ordovician globe.

The relative water depth inhabited by the Oriel Brook fauna was obtained from a different cluster analysis; this fauna was shown to lie in the deeper end of the relative water depth spectrum. Subsequently, the Oriel Brook fauna was more accurately placed in mid to deep depth of the relative water depth spectrum by both seriations. This supports the findings of an earlier study by Harper and Mitchell (1982), who state that Oriel Brook's brachiopod fauna laid closer to a shallow relative water depth of BA3-4, rather than to the characteristic greater depth (BA5-6) of other known *Foliomena* faunas.

This evidence now provides answers to the questions posed in this study. It shows that the Oriel Brook brachiopod fauna is indeed a deep water *Foliomena* fauna, but that, unlike most other faunas, it inhabited a shallower depth on the relative deep-water depth spectrum, and that it shares the closest similarity to those faunas that inhabited the Iapetus region of the globe during the late Katian. As a result, this study has also demonstrated the ability of Palaeontology to construct and correlate changing continental configurations through time, and to reconstruct ancient environments. Indeed, fossils have been depicted as vitally important 'tools' which tell a story. However, Palaeontology is also of key relevance to the future, particularly through the documentation of the evolutionary radiation and extinction of life on Earth (Wyse Jackson, 2012). This was implied in this study, as the Oriel Brook fauna dates back to the same time that deep-water *Foliomena* faunas had begun to adapt to shallower water depths (Sheehan, 1973; Rong et al., 1999; Renbin et al. 2010). This adaptation to evermore shallow relative water depths (as shallow as BA2) would prove a fatal evolutionary move (Rong and Zhan 1996; Rong et al., 1999). It had coincided with the end Ordovician mass extinction event, the first of the 'Big 5' mass extinctions to occur in Earth history, which include the much better-known dinosaur extinction (Harper and Rong, 1995; Sheehan, 2001). This first mass extinction event was just as significant, but not as simple as an asteroid impact, which experts believe killed the dinosaurs (Alvarez et al., 1980). Many authors believe the end-Ordovician mass extinction was caused by abrupt climate change, initiating a short, severe ice age (Brenchley et al., 1994; Benton & Harper, 2009; Wyse Jackson, 2012). The *Foliomena* fauna was killed off during the first pulse of this extinction event, recorded by the last appearance of the brachiopod *Chonetoidea* in the rocks of Morocco (Renbin et al. 2010; Candela, 2011). Then positioned at the south pole, these brachiopods would have been among the first to perish at the hands of falling sea levels and advancing glaciers. The other *Foliomena* faunas, along with ~85% of all life at the time, would soon follow (Benton & Harper, 2009). Despite persisting for some 15 million years, at various water depths and regions around the world, the extinction of the *Foliomena* fauna serves as an important message for our future. With some scientists warning that we are entering a sixth extinction (Ceballos et al., 2017), Palaeontology proves evermore relevant in discussions concerning our actions and their long-lasting consequences on the future of the planet.

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