

# An interim global bioregionalisation of Devonian areas

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## Abstract

We present an interim Devonian bioregionalisation in which previous zoogeographical and biogeographical areas of Devonian taxa are reviewed. This review has been long overdue, as Devonian bioregionalisation has become poorly constrained since the foundational work of Arthur J. Boucot in the late 1960s. A systematic review of over 100 areas and amendments is completed for the first time with addition of three new areas: the Mardoowarra and the Late Devonian Eastern Australasia region, and Western Gondwana realm. This interim regionalisation is the first to be completed and standardised, made in preparation for future palaeobiogeographic studies and as a prelude to rigorous testing. By standardising the 1969 bioregionalisation of Boucot et al. Devonian biogeography can begin to assess if the proposed bioregionalisation is representative of true natural areas.

**Keywords** Area nomenclature · Biogeography · Eastern Americas · Malvinokaffric · Old World · Palaeobiogeography

## Introduction

Multi-taxon global bioregionalisations have been the backbone of both biogeographic (Sclater 1858; Wallace 1876) and palaeobiogeographic studies (Arlt 1907; Schuchert, 1909). The descriptions of areas and their nomenclature (sensu Wallace 1894; Arlt 1912) have been vital to maintaining existing bioregionalisations, reducing the number of conflicting terms and descriptions. While these practises were prevalent in the early twentieth century, they have become neglected after the 1960s. The modern single-taxon global bioregionalisations appropriate terms from previous multi-taxon approaches, resulting in numerous revisions of areas such as ‘Gondwana’ and ‘Australasia’. Devonian bioregionalisation had also suffered the same fate.

Arthur J. Boucot (1924–2017), established the framework for a hierarchical global Devonian area classification shortly after the plate tectonic revolution of the 1960s (Boucot et al., 1969). After the presentation and revisions of Boucot’s work, Devonian bioregionalisation became an active field with a plethora of authors challenging (Bowman Bailey, 1978;

Kobayashi and Hamada 1975; Young, 1981, 1986) or supplementing Boucot’s original regions (Hou, 1981; Bigey 1985; Blodgett et al., 1990; Afanasieva and Amon, 2013; amongst others). Additionally, the bioregionalisation of Boucot et al. (1969) despite its revisions and amendments has never been completed with areas left unassigned. This incomplete bioregionalisation, without any checks on the use of names or their definitions, has been foundational in many subsequent biogeographic studies. Consequently, this has led to a confusing set of single-taxon bioregionalisations and unstable *area taxonomy* (a hierarchical classification of names see Ebach and Michaux 2017).

This paper aims to review and standardise global marine Devonian bioregionalisation into single, interim area taxonomy for use in future bioregionalisation studies.

## A practitioner driven field

Bioregionalisations and area classifications have been a feature of the natural sciences since the nineteenth century. The consideration of bioregionalisation and taxic distributions have proven a key tool for palaeoreconstructions and instrumental in the development of geological theories such as continental drift. Prior to Boucot, palaeogeographers characterised areas using unranked and unstructured terms such as geographical realms (e.g. Old World, Old Red Continent), geological distributions (e.g. basins, formations, assemblages), or the continents themselves (e.g. North America, Gondwana,

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Lemuria, Archiplata; see Suess, 1885; von Ihering, 1892; Schuchert, 1903, 1909).

Most notable in raising the issue of nomenclature was Anthony Hallam who remarked that “of the older literature bearing on past continental relationships, as summarised for instance by Arldt (1919–1921), has required or still requires critical revision in the light of modern knowledge and the more rigorous standards of today” (Hallam, 1966, p. 204).

Although Hallam was commenting on bioregionalisation in general, the framework for a formal Devonian area classification is largely due to Boucot (Boucot et al., 1969; Boucot and Gray, 1974; Boucot, 1985, 1988, 1993; Boucot and Blodgett, 2001; Boucot et al., 2008). Boucot used overlapping distributions constrained by geological and geographical features to delineate his areas and brought structure to the nascent field. However, relics of prior approaches remained within his work, for instance the use of ‘Old World’ (e.g. *Orbis Terrarum Veteribus* Jansson 1650; *Orbis Vetus* Sanson 1657), a cartographical term used to describe Europe, Africa and Asia goes back to seventeenth century after the discovery of the New World (North and South America). Consequently, Boucot’s areas are open to scrutiny.

Kobayashi and Hamada (1975), abandoned the idea of the Old World, while others remained in favour (Chlupac, 1975; Cocks and McKerrow, 1973; Bigey, 1985; Blodgett et al., 1990; Hallam, 1994). Further discoveries of taxa and their distributions led to areas being added and subtracted in any given bioregionalisation. For example, two of the three realms proposed by Boucot et al. (1969), the Eastern Americas and Malvinokaffric realms were eliminated or reduced in the Late Devonian, resulting in two equally unlikely eventualities: (1) either the Old World realm was global in distribution (an impossibility due to its shallow, warm-water characteristics) or (2) that despite the maintenance of regions and provinces, those outside of the bounds of the Old World realm existed within an undefined, unranked area. To assist in the resolution of this problem, three new areas have been proposed to complete the bioregionalisation of the Late Devonian.

Though the bioregionalisation of Boucot et al. (1969) has been reconsidered by various authors using alternate taxa (such as Kobayashi and Hamada, 1975), it remains the standard by convention amongst palaeobiogeographers. As a consequence, alternative bioregionalisations not considered here. With over 100 biotic areas named since Boucot’s framework was established, we feel it is timely to systematically review known Devonian biotic areas including the stratigraphic range, distribution and diagnosis of realms, regions and provinces. The following systematic review is in character with Boucot’s original classification, although several ranks have been recast to form a more stable bioregionalisation (Table 1). Each area of realm, region or province rank will be given a standardised nomenclature, reviewed and their subprovinces listed.

## A note on area nomenclature

The stability of any area taxonomy lies in the strength of its nomenclature. Since Boucot et al. (1969), the competing nomenclature of authors has seen variability in biogeographic taxonomic rank. For instance, compare the New Zealand region (Boucot and Gray, 1979) and the New Zealand province (Young, 1981), or the Malvinokaffric realm (Oliver, 1977) and the Malvinokaffric province (Boucot et al., 1969) and the confusion in comparing ranks both spatially and temporally. Despite the few attempts to establish a formal biogeographic nomenclature (e.g. Cecca and Westermann, 2003; Ebach et al., 2008; Servais et al., 2013), very few authors describe their process for establishing hierarchy and even fewer justify new area names (e.g. Lebedev and Zakharenko, 2010) or reasons for the maintenance of Boucot’s original hierarchy across differing taxa (Oliver, 1977; Bigey, 1985 amongst others).

For the purpose of this study the *International Code of Area Nomenclature* (ICAN) (Ebach et al., 2008) will be applied to all biogeographical areas as it makes the least number of assumptions concerning area definition and focuses on area nomenclature, rather than on ecological history or, evolutionary, ecological or biogeographic processes (*sensu* biochores/bichorema, Westermann, 2000; Yanin, 2010; Servais et al., 2010). To formalise each named area, the ICAN requires area names to be designated a name-bearing type locality and a diagnosis, in which areas may be synonymised. The types are taken from the studies that established the biogeographic area. Types will be the formation, group, series, or basin at higher ranks, within which are found the characterising taxa. If the author(s) of the original studies do not provide a locality, selection was made by using the same approach.

The ICAN is vital for preserving names and acknowledging synonymies. The ICAN has been used extensively in extant bioregionalisations across various phyla (Albert and Reis, 2011; López et al., 2008; Lumbantobing, 2010; Escalante et al., 2013; Costa et al., 2013; Neubauer et al., 2015; Van Rooy and Van Wyk, 2010; Postigo Mijarra et al., 2009; Ebach et al., 2013, 2015; Morrone, 2014, 2015a,b). The usage of the term ‘region’ is an exception, for though it is considered by Cecca and Westerman (2003) to be ‘informal’, within the ICAN ‘region’ is considered a rank above ‘province’ and one rank below ‘realm’.

## Ambiguous names and concepts

### Zoogeography

The zoogeographic practise of naming areas after their characterising taxa (for example, the Sinogaleaspid-Xiushuiaspid realm of Pan and Dineley, 1988) does not allow for standardisation. Biogeographic areas are established based upon the shared distributions of multiple taxa (*sensu* area of

**Table 1** The ages of realms, regions and provinces within the Devonian

Realm	Region	Province	Lochkovian	Pragian	Emsian	Eifelian	Givetian	Frasnian	Famennian
Eastern America	N/A	Appohimchi	██						
		Nevada	██						
		Michigan Basin	██						
		Venezuela-Colombia	██						
Malvinokaffric	N/A	██							
Old World	Cordilleran	Alaska-Yukon	██						
		Euramerican	██						
		Western Canada	██						
		Nevada	██						
		Mackenzie	██						
		Eastern Australasia	██						
	New Zealand	██							
	Rhenish-Bohemian	North Africa	██						
		Tasman	██						
	East Australia	██							
	Mardoowarra	██							
	South China	Junggar-Xinan	██						
		South China	██						
		Uralian	██						
	Balkash-Mongolo-Okhotsk	██							
	Siberian	██							
	Ural-Southern Tianshan	██							
	Tuva	██							
	Western Gondwana	██							

endemism; reviewed in Parenti and Ebach 2009). The use of characterising organisms as area nomenclature encourages the alteration of area names when the ‘typifying’ taxa decreases its influence or is replaced.

*Phytogeography*

Devonian plant biogeography (phytogeography) is an under-represented aspect of the field. Some Devonian phytogeography related instead the distribution of characteristics (Raymond, 1987) or were indeterminate in their characterisation (Hart 1976). Furthermore, studies in phytogeography (Edwards (1973, 1990) Streel et al., 1990, Rowley et al. (1985) Steemans et al., 2007, de Pasquo et al. 2009, Berry et al. 2000 among others) rarely engage with the marine

regionalisations of Boucot et al. (1969) and would require their own review of bioregionalisation. As a consequence phytogeographic regions are omitted from this review.

*On the exclusion of planktonic areas*

Afanasieva and Amon (2013) published a comprehensive analysis of Devonian radiolarian distributions and established four provinces and six subprovinces. The incompatibility of planktonic distributions with other faunal groups has been acknowledged by Afansieva and Amon (2013). As a consequence, their bioregionalisation, along with those on other planktonic organism such as by Klapper (1975), Fahraeus (1976) and Klapper and Johnson (1980), has been omitted from the review, used instead as supporting evidence.

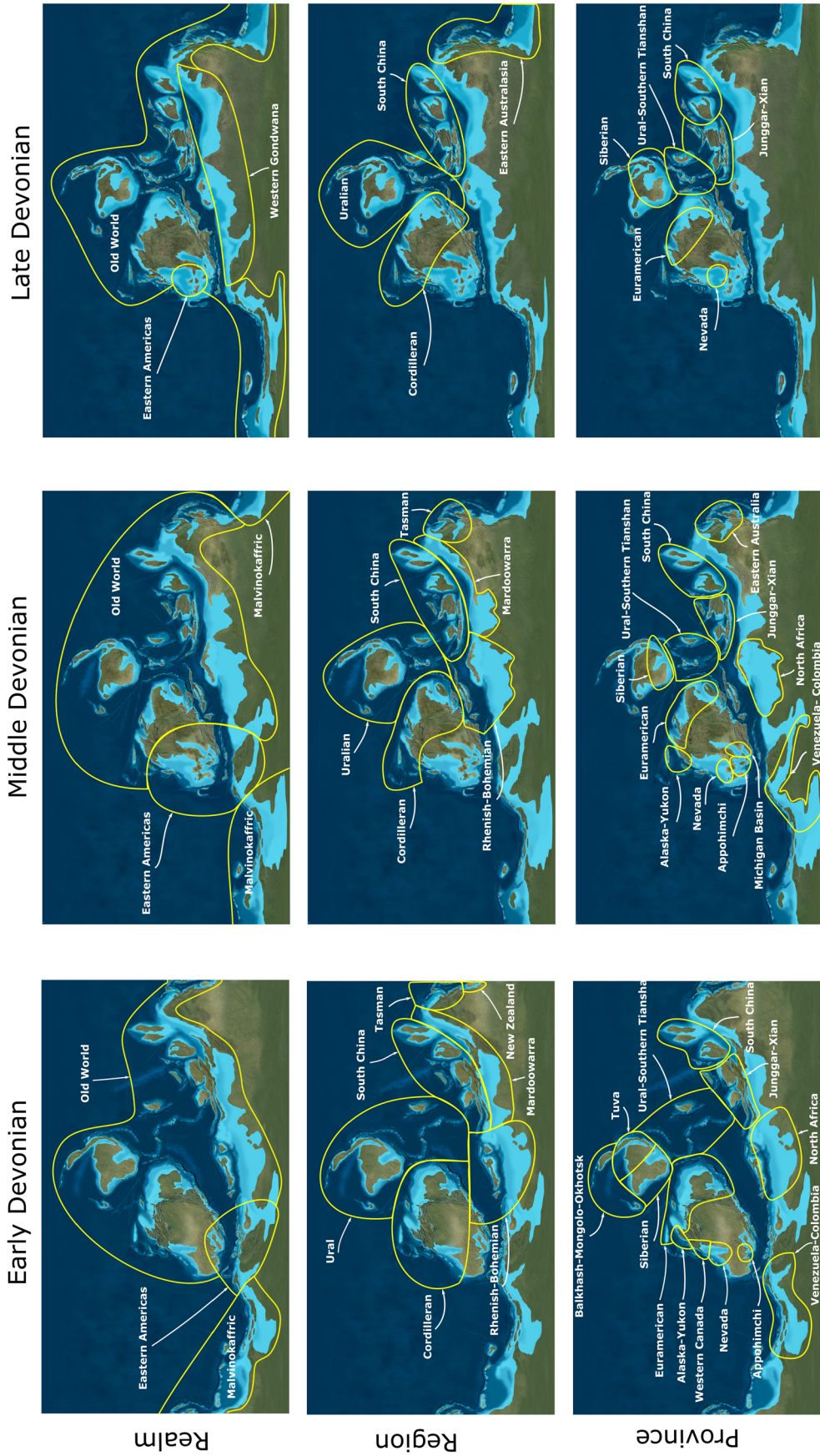


Fig. 1 The realms, regions and provinces of the Early, Middle and Late Devonian. Maps modified by the authors. Base maps copyright Ron Blakey, Colorado Plateau Geosystems, Inc.



## Systematic review of Devonian areas

### Area taxonomic note

The interim area taxonomy herein (Table 1) adheres to the conventions of a systematic palaeontology with the following hierarchy outlined in the ICAN: realms, regions, provinces and subprovinces. All areas with the exception of subprovinces have a name, synonymy, stratigraphic range, type and diagnosis. As in a biological taxonomy, the diagnosis is purely descriptive. A remarks section is provided to summarise any existing biogeographic syntheses or hypothesis. The regionalisation is mapped according to Devonian age (Fig. 1).

### *Eastern Americas realm*

Appalachian province Boucot et al., 1969

Eastern Americas realm Boucot, 1974

Appalachian province Hou, 1981

**Stratigraphic range:** Early Silurian–Carboniferous (Boucot et al., 1980; Bigey, 1985; Oliver, 1990; Li, 2010).

**Type:** Appalachian Basin; New York, Pennsylvania, eastern Ohio, West Virginia, western Maryland, eastern Kentucky, western Virginia, eastern Tennessee, northwestern Georgia and northeastern Alabama.

**Diagnosis:** Warm-water unit with a highly endemic fauna such as the gastropods *Pleuronotus*, *Trochonema* (*Trochonemopsis*), *Elasmonema*, *Isonema*, *Turbonopsis*, *Palaeotochus*, spinose platyceratids, *Protolptosrophia* and *Plicoplasia* (Blodgett et al., 1990; Hallam, 1994). Silurian holdovers are considered unimportant within the Eastern Americas realm, though some are identified in the Appalachian Basin during the Gedinnian (Hallam, 1994). Extends to include areas south of the Central Canadian Shield (i.e. Michigan and Appalachian Basins, Venezuela and Colombia) and much of North America east of the transcontinental arch (Boucot, 1974; Boucot et al., 1980; Oliver, 1990; le Herisse et al., 1997).

A warm-water unit with connection, via a surface current, to the Malvinokaffric boundary in NW Argentina (Boucot et al., 1980). The border shared with the Malvinokaffric is positioned midway between the southern margin of the Amazon Basin, passing through the Parnaiba basin, and the northern margin of the Parana Basin (Boucot et al., 2001). During the Devonian the unit was seen as the intermediate between the Malvinokaffric and the Old World realms (Boucot, 1974; Wang et al., 1984).

**Remarks:** During most of the Early and Middle Devonian the Eastern Americas realm was bordered by land on three sides; the cycles of regression and transgression that existed throughout the Devonian rendering the barriers to dispersal periodically ineffectual (Oliver, 1976; Li, 2010). The reduction of the surrounding barriers saw Lochkovian connections

to the Great Basin, resulting in Old World elements within the brachiopod assemblages of Chihuahua Mexico (Oliver, 1976).

The Eastern Americas realm could not be differentiated from the Old World realm during the Eifelian, coincident with the Emsian transgression and increasing cosmopolitanism of the Eifelian (Li, 2010). Oliver (1990) noted the disintegration of provinces (based on rugose corals) was delayed until the Frasnian, when the realm ends transitioning into more cosmopolitan forms. However, the strict delineation of the realm requires reconsideration. Problems of the Eastern Americas realm's area nomenclature include the lack of clarification from authors regarding the upper or lower limits of each area proposed, also provinces and subprovinces are often used interchangeably (e.g. compare Boucot, 1974; Oliver, 1990; Li, 2010). In addition, Oliver (1977, 1990) is consistent in his use of terms (e.g. basins and areas with the same endemic fauna remain as provinces).

Warm-water incursions into the Eastern Americas realm from the Cordilleran region during the Kačák event may have increased Old World realm transport into the Appalachian, Michigan and Iowa Basins and to a lesser extent the Wabash Platform area (i.e. Ohio and South East Indiana in the US) (DeSantis and Brett, 2011). Original designations saw the Eastern America realm terminate in the Eifelian; however, the Nevada province maintained a distinctive element into the Late Devonian and to avoid an incomplete bio-regionalisation, the realm's duration has been extended.

### *Appohimchi province*

Appohimchi province Oliver, 1977

**Stratigraphic range:** Lochkovian to Frasnian (Oliver, 1990; Boucot and Blodgett, 2001).

**Type:** Onondaga formation, Eifelian (Bigey, 1985), New York State to Maryland.

**Diagnosis:** Warm-water fauna with significant coral diversity including Heterophrentidae, Zaphrentidae and Craspedophyllidae amongst others (Oliver, 1990). During the Lochkovian to the Eifelian, the area was distributed across Eastern North America and became restricted to the Appalachian belt from the Eifelian to the Frasnian (Oliver, 1990).

**Remarks:** Taxa used for differentiation were not observed within the proximal basins and provinces of the Eastern Americas realm, though there was strong evidence for some faunal exchange between the basins of the Eastern Americas realm during the Emsian and subsequent transgressive cycles. Emsian Old World affinities were observed within the geographical area of the Appohimchi province by Amsden et al. (1968) and Ormiston (1968) (see Oliver, 1977).

### *Nevada province*

Nevadan subprovince Boucot et al., 1969

Nevada province Oliver, 1977

Great Basin province Pedder and Murphy, 2004

**Stratigraphic range:** Middle Devonian (Oliver 1990, Boucot and Blodgett, 2001; Pedder and Murphy, 2004).

**Type:** The Great Basin, including Nevada, eastern Oregon, southern Idaho and the Colorado River watershed (including the Las Vegas metropolitan area and the northwest corner of Arizona).

**Diagnosis:** A warm-water unit that underwent deepening due to the west to east transgression over the Transcontinental arch (Blakey, 2008). The platform, on shore peripheral fauna (Bigey, 1985) including the brachiopods *Megakozłowskiella*, *Leptocoelia*, *Pleiopleurina*, *Levenea*, *Acrospirifer*, *Echinocoelia* and *Costispirifer*. For faunal list, see Oliver (1990) and Boucot et al. (1969). Despite being distributed primarily across the Great Basin (southwest North America), the area of Western North America was annexed into the Eastern Americas realm during the lower Early and Middle Devonian (Oliver, 1990).

**Remarks:** Significant faunal exchange between the Appalachian province and the Old World realm saw the Great Basin annexed into the Eastern Americas realm during the Middle Devonian. The Great Basin was highly endemic, specifically seen within benthic fauna, allowing significant differentiation from the adjoining Western North America (Oliver, 1990). In the Early Devonian, the genera of the Great Basin were of Appalachian affinity but expressed divergence at the species level (Boucot et al., 1969).

#### *Michigan Basin province*

Michigan Basin province Olivier, 1990

**Stratigraphic range:** Early Eifelian to late Givetian (Oliver, 1990).

**Type:** Michigan and Hudson Bay Basins including Illinois, Iowa (Oliver, 1990).

**Diagnosis:** Coral fauna including *Acrophyllyum*, *Argutastrea*, *Hexagonia* (see Oliver, 1990 for full list) and the presence of Appohimchi coral fauna (Bethanyphyllidae). Distributed across the Michigan and Hudson Bay Basins including Illinois and Iowa (Oliver, 1990).

**Remarks:** Separated from the Appohimchi province at the start of the Eifelian coincident with the end of a transgressive stage. Unique identity defined despite significant Appalachian influence within the province (Johnson et al., 1985; Oliver, 1990).

**Subprovinces:** Michigan Basin-Hudson bay subprovince (Boucot and Blodgett, 2001).

#### *Venezuela-Colombia province*

Venezuelan-Colombian province Oliver, 1977

**Stratigraphic range:** Early Devonian to early Givetian (Oliver and Pedder, 1989; Oliver, 1990).

**Type:** Rio Cachiri Group, Venezuela.

**Diagnosis:** Warm-water unit of Western European affinities and significant coral assemblages including *Bowenelasma*, *Cylindrophyllum* and affinity with Eastern North America corals in the Eifelian (Oliver, 1977). Few fenestellids were recorded from the Venezuelan Rio Cachiri Group with diverse bryozoan assemblages observed in Colombia's eastern Cordillera including fenestellids, ptilodictyids and fistuliporids from the Floresta Formation (Bigey, 1985). The unit was distributed across the Colombian-Venezuelan Basin.

**Remarks:** Corals were rare in the surrounding area but persisted within the province (Oliver, 1977). The area is considered an extension of the Appohimchi province into northern South America and recognition of *Bowenelasma* in New York, Northern America (Oliver, 1990).

**Subprovinces:** Amazon-Colombian subprovince, the latter of which was subsequently split into the Amazon and Colombian subprovinces (Boucot and Blodgett, 2001; see Pedder and Murphy, 2004). Colombian subprovince Early-Middle Devonian (Boucot and Blodgett, 2001.). Amazon subprovince Early -Middle Devonian (Boucot and Blodgett, 2001).

#### *Malvinokaffric realm*

Malvinocaffrische province Richter, 1941

Malvinokaffric province Boucot et al., 1969

Austral realm Chlupac, 1975

Malvinokaffric province Kobayashi and Hamada, 1975

Malvinokaffric realm Johnson and Boucot, 1973

Malvinokaffric realm Blodgett et al., 1990

Malvinokaffric province Anderson et al., 1999

**Stratigraphic range:** Early Devonian, with decline beginning in the late Emsian (Boucot et al. 1969) and final termination in the Givetian (Hallam, 1994; Holmquist 2008; Cocks, 2011; Aboussalam and Becker, 2011, de Melo, 1988).

**Type:** Chapada group, Paraná Basin from Mato Grosso to Rio Grande do Sul states, Brazil (Bosetti et al., 2011; Becker-Kerber et al., 2017).

**Diagnosis:** Restricted low diversity, often cold, deep-water faunas within dark terrigenous clastic lithofacies with detrital, unweathered mica lacking warm weather indicators (Boucot, 1984; Meyerhoff et al., 1996). Arctic to temperate climate but without glaciation, few corals, comparatively depauperate but with endemic brachiopod genus *Australostrophia* and a dominant *Orbiculoidea falklandensis* and homonalotid trilobite (*Burmeisteria*) presence across the realm (Oliver, 1977;

Copper, 1998; Boucot et al., 2001). Typical brachiopod genera include *Scaphiocoelia*, *Pleurothyrella*, *Notiochonetes*, *Tanerhynchia*, *Australispirifer*, *Notiochonetes*, *Australocoelia*, *Pleurothyrella* and an endemic species of *Schellwienlla* (Boucot et al., 1969; Cocks 2011). Trilobite fauna include Phacopinae, Calmoniinae, Acastavinae and Asteropyginae with endemic species of the Homalonotidae (Kobayashi and Hamada, 1975). The Bokkeveld series is considered Malvinokaffric based upon fish fauna such as *Machaeracanthus* and chondrichthyans (Young, 1987; Long et al., 1988; Anderson et al., 1999).

Boucot et al., 1969 first identified the realm (then province) to include South America, southernmost Africa and Antarctica. During the Early Devonian the Malvinokaffric included West Africa from Ghana to South Africa, Antarctica, South America south from Lake Titicaca region and Matto Grosso south (Boucot et al., 1969; Boucot, 1985; Oliver 1990; Hallam, 1994).

**Remarks:** The Devonian Malvinokaffric realm is believed to have originated from the Appalachian basin in the Silurian (Koch and Boucot, 1982; Hallam, 1994). The Silurian Malvinokaffric, one of the two predominant Silurian realms, provided no taxonomic continuity to that of the Devonian due to the terminal Silurian extinction (Berry and Boucot, 1970; Boucot, 1985; Hallam, 1994; Meyerhoff et al., 1996; Blodgett and Stanley, 2008). Chlupac (1975) noted the trilobite *Phacops* (*Phacopina*) was present within both the Malvinokaffric and Eastern Americas realm, though in low diversity and high abundance within the former realm. Interestingly, by the Lower Devonian, no Malvinokaffric realm brachiopods were observed within the Eastern American realm (Boucot et al., 2001). Transport between the realms was apparently one way with Eastern America realm brachiopods (*Australocoelia*, *Australispirifer* and *Plicoplasia*) present within the Malvinokaffric realm (Oliver, 1990; Boucot and Blodgett, 2001; Li, 2010).

Due to the cold water of the Malvinokaffric realm bryozoans, corals, conodonts, calcareous algae, nautiloids, stromatoporoids, bioherms and the significant brachiopod taxa *Atrypida* and *Gypidula* were notably absent (Oliver, 1977, 1990; Koch and Boucot, 1982; Meyerhoff et al., 1996; Hallam, 1994; Boucot et al., 2001). Gastropod diversity was lowest within the Malvinokaffric realm, absent within the Lochkovian, emerging within the Pragian and Emsian and absent by the Givetian (Blodgett et al., 1990).

Throughout the Early Devonian the Malvinokaffric realm degenerated until final termination in the Givetian, though it maintained an endemic fauna until the Famennian (Boucot, 1985; Hallam, 1994; Meyerhoff et al., 1996; Blodgett and Stanley, 2008). Due to an abrupt Early Devonian global warming event the geographical distribution of the Malvinokaffric realm was reduced (Oliver, 1990; Boucot et al., 1969; Boucot, 1988). This extinction event reduced shelled fauna genera from 65 to 8 within the Parana Basin (Bosetti et al., 2011). The Malvinokaffric trilobites became

extinct in the late Givetian coincident with the abrupt dispersal of warm-water taxa (House 1978; Leanza 1968; Boucot and Theron, 2001; de Melo, 1988; Aboussalam and Becker, 2011). Strong warming pulse in the late Givetian led to a lowering of the latitudinal temperature gradient, compounded by eustatic fluctuations, resulted in the restriction of the Malvinokaffric which continued throughout the Taghanic event (Aboussalam and Becker, 2011).

Evidence from the brachiopods *Australocoelia* and *Pleurothyrella*, *Tanerhynchia* distributions suggests South Eastern Australia (Tasmania and Victoria) and New Zealand were proximal to the Malvinokaffric realm's boundary with the Old World realm (Boucot et al., 1969).

#### Old World realm

Old World province Boucot et al., 1969

Old World realm Boucot and Gray, 1979

Old World realm Bigey, 1985

**Stratigraphic range:** Earliest Devonian to Carboniferous (Blodgett et al., 1990).

**Type:** Prague Basin (Chlupac, 1975) Bohemian Massif; Czech Republic.

**Diagnosis:** Equatorial realm with the highest levels of diversity and warm-water features such as carbonates, shallow subtidal fauna, reef or bioherm and evaporites (Chlupac, 1975; Blodgett et al., 1990; Hallam, 1994; Cocks and McKerrow, 1973). The Old World realm was derived from the Silurian 'North Silurian realm' (Boucot, 1974) and had significant Silurian holdovers such as eospirifers, orthids, atrypids, athyridids (Boucot et al., 1969; Boucot, 1985; Hallam, 1994). Eurasia was characterised by the trilobites *Acaste*, *Asteropyge*, *Neometacanthus*, *Treveropyge* and other asteropygids and *Homalonotus* with the trilobites traceable through South Asia and into Chitral, Pakistan (Kobayashi and Hamada, 1975).

Observed across western and arctic North America, Eurasia, North Africa, Australia, annexing part of the Eastern Americas and Malvinokaffric realms throughout the Middle to Late Devonian as extinction event compounded increasing global cosmopolitanism (Hallam, 1994; Boucot, 1985; Bambach, 2006).

**Remarks:** First identified by Boucot et al., (1969), the Old World realm is divided into the Rhenish-Bohemian, Uralian, Cordilleran, Tasman, Mardoowarra, Eastern Australasia and New Zealand regions.

Since the classification of Boucot et al., (1969) multiple authors have reiterated the realm (Oliver, 1977; Bigey, 1985; Wang et al. 1984; Lieberman and Eldredge, 1996; Blodgett et al. 2001; Bossetti et al., 2011; Aboussalam and Becker, 2011 amongst others). The Old World saw Early Devonian provincialism steadily increase until it reached its maximum within the Emsian, with some fauna, such as rugose corals, presenting 91% endemism in some areas (Oliver, 1976). The

transcontinental arch, which separated Devonian seas in the eastern and western North America, was an effective barrier to exchange between the Eastern Americas and the Old World realms, the cycles of transgression and regression resulting in local submergence and potentially contributing to the decrease in provincialism due to exchange and competition (Oliver, 1976; Rode and Lieberman, 2005). Old World realm genera, for example, have been located within the Michigan Basin and Hudson Bay lowland which led to the conclusion that a viable marine connection to the Old World existed (Kobayashi and Hamada, 1975; Van Der Voo 1988; Blodgett et al., 2002). Oliver (1976) notes that Old World fauna had dispersed to the Eastern Americas in greater numbers and with greater success.

The high rates of endemism in the Early and Middle Devonian waned into the Late Devonian (Young, 1981; Young et al., 2010). Zhao and Zhu (2010) proposed three Asian dispersal routes connecting Laurentia and Gondwana: the overlap of the northern, southern and circum-pacific ocean routes. These dispersal routes allowed shared brachiopod fauna between the Chinese terranes and Europe, North America, Siberia and Gondwana (Chen, 2004). Vertebrate fauna indicates similar patterns with Iran, Afghanistan, Azerbaijan, Saudi Arabia, Turkey, Bohemia, France, Spain, Portugal, Bolivia, Venezuela, Colombia, Morocco, Libya, Algeria and South Africa presenting specific resemblance to Chinese species (Zhao and Zhu, 2010).

#### *Cordilleran region*

Cordilleran subprovince Boucot et al., 1969

Uralian-Cordilleran region Boucot, 1974

Cordilleran region Blodgett et al., 1990

**Stratigraphic range:** Devonian (DeSantis and Brett, 2011).

**Type:** Road River Group, Alberta.

**Diagnosis:** Warm-water western North American brachiopod fauna including *Variatrypa arctica*, *Pentamerella*, *Spinatrypa* and *Warrenella* (*Warrenella*) *maia* and the rugose coral *Guerichiphyllum* (DeSantis and Brett, 2011). The Eifelian Stony Hollow Event resulted in the disappearance of *Variatrypa* from Eastern Laurentia, the fauna persisting within the Cordilleran region (DeSantis and Brett, 2011). Western and Arctic North America (Nevada, southern California, British Columbia, Alberta, Manitoba, Yukon Territory, Northwest Territories and the Canadian Arctic Archipelago).

**Remarks:** The Cordilleran region was situated within subtropical equatorial regions, distributed throughout interior and southeastern Alaska, Canada and western America (Morrow and Geldsetzer 1988; DeSantis and Brett, 2011; Wang et al., 2011). The region presents great diversity, including shell ornamentation potentially due to the migration and association with the Eastern Americas realm, particularly Appalachian brachiopods, gastropods, corals (DeSantis and Brett, 2011). Warm-water incursions from the Cordilleran region during the Kačák

Event were observed from within the Appalachian, Michigan and Iowa basins and to a lesser extent the Wabash Platform area (Ohio and southeast Indiana (DeSantis and Brett 2011). Indicative of the Stony Hollow Event (late Eifelian) was the sudden expansion of the Cordilleran taxa into North America.

In the Early Devonian the Nevadan subprovince was relegated to the Eastern Americas realm its affiliation shifting in the Emsian, becoming distinctly Old World during the Eifelian (DeSantis and Brett, 2011). Originally based upon evidence from rugose corals and brachiopods, Pedder and Murphy (2004) argued that Rugosa no longer supported the Pragian brachiopod evidence that the Nevada platform biofacies were a western extension of the Eastern Americas realm into the Cordilleran province (Pedder and Murphy, 2004).

**Subprovinces included:** Cordilleran subprovince a subset of the Great Basin (Boucot et al., 1969; Kobayashi and Hamada, 1975). Alaska-Yukon subprovince (Blodgett et al., 1990, see Alaska-Yukon province). Nevada subprovince (Blodgett et al., 1990).

#### *Alaska-Yukon province*

Alaska-Yukon subprovince Boucot, 1974

Alaska-Yukon subprovince Blodgett et al., 1990

Alaska-Yukon province Pedder and Murphy, 2004

**Stratigraphic range:** Eifelian (Blodgett et al., 1990).

**Type:** Nixon Fork terrane, Canada.

**Diagnosis:** Gastropods related to coeval forms in northwestern Canada. Interior and southeastern Alaska, the subprovince covers the Nixon Fork Terrane and Livengood terrane (Blodgett et al., 1990).

**Remarks:** The area distributed across the Nixon Fork and Livengood terranes, which is poorly constrained within the biogeographical hierarchy (Boucot, 1974; *contra* Blodgett et al., 1990). Limited to southeastern Alaska, its contemporaneous Early Devonian relationships tend towards northwestern Canada, suggesting a displacement of Alaska's 'suspect terranes'. The subprovince was an equatorial area that remained separated from the Great Basin of the Nevada province based upon rugose coral data (Blodgett et al. 2001; Pedder and Murphy, 2004).

#### *Euramerican province*

Euramerica (Cephalaspid) province Young, 1981.

Euramerica province Afanasieva and Amon, 2013.

**Stratigraphic range:** Devonian.

**Type:** Timan-Pechora basin

**Diagnosis:** Defined by traquairaspids, pteraspids and cyathaspids across North America, the Canadian arctic and



Greenland (Young, 1981). The unit has radiolarian associations within marginal seas and shallow shelf epiplatforms.

**Remarks:** The province spans the entirety of the Devonian and is characterised by shallow shelf epiplatform and marginal sea environments (Afanasieva and Amon, 2013). This province, due to its large spatio-temporal distribution falls within both the Cordilleran and Ural regions of Boucot (1974). The region is assigned here to the Cordilleran region due to its prominence within western North America. Breakdown of subprovinces hypothesised due to the convergence of Baltica (Europe west of the Urals) with Laurentia and the consequent end of geographical barriers (Young, 1981).

**Subprovinces included:** European subprovince, North American subprovince, Northern subprovince (Afanasieva and Amon, 2013).

#### *Western Canada province*

Western Canada province Boucot and Blodgett, 2001

**Stratigraphic range:** Early Devonian

**Type:** Hare Indian and Ramparts formations, Mackenzie Mountains, Canada.

**Diagnosis:** Gastropod fauna including *Tropidodiscus*, *Boiotremus*, *Bellerophon*, *Kodymites*, new genus *liospirinid*, *Stenoloron*, *Australonema*, *Platyceras*, *Orthonychia*, *Oriostoma*, *Semitubina*, *Murchisonia*, *Planitrochus* and *Perneritrochus* (Blodgett et al. 2001). Miogeoclinal shelf areas of British Columbia, southwestern Northwest Territories and the triangular, non-accreted portion of east-central Alaska.

**Remarks:** The Early Devonian brachiopod faunas of the Western Canada province were almost entirely distinguished from those in adjacent Alaska, which later accreted to the margin (Blodgett et al. 2001). While both Western Canadian and Alaskan accreted terranes were Old World, the fauna of the Western Canada province bore Uralian affinity.

#### *Nevada province*

Nevada province Boucot, 1974

Great Basin province Pedder and Murphy, 2004

**Stratigraphic range:** Early Devonian.

**Type:** Colis Creek member, McColley Canyon Formation, northern Roberts Mountains, eastern central Nevada.

**Diagnosis:** The Great Basin west of the transcontinental arch. Depauperate brachiopod fauna. In the early Pragian the province exhibited a low diversity fauna. The province began to decline in the late Emsian with the disappearance of Breviphyllidae and Papiliophyllidae was finally terminated with the early Eifelian arrival of the Old World realm Cystiphyllidae, Ptenophyllidae and Stringophyllidae (Pedder and Murphy, 2004).

**Remarks:** The Nevadan province was annexed by the Eastern America realm at the start of the Eifelian (Boucot, 1974). The Nevada province was primarily distinguished by the fauna of the Great Basin (Boucot, 1974) and despite being in close proximity to the Mackenzie and Appohimchi provinces each were distinct in the Pragian and Emsian (Pedder and Murphy, 2004).

#### *Mackenzie province*

Mackenzie province Pedder and Oliver, 1990

**Stratigraphic range:** Pragian to Eifelian.

**Type:** Bartine Member, western central Nevada.

**Diagnosis:** Prominent coral fauna including Mucophyllidae, Spongonariidae, or Ptenophyllidae with the sole representative of Papiliophyllidae. Nevada, bound by the allochthonous Alexander and Farewell terranes of Alaska and British Columbia (Pedder and Oliver, 1990).

**Remarks:** The province is defined in the middle Pragian by 28 genera of which 27 are absent from Great Basin and all are absent from Appohimchi province. The strict generic differentiation within corals was used by Pedder and Murphy (2004) to further define previous provinces established by brachiopods (Boucot, 1974) and gastropods (Blodgett et al. 2001).

#### *Eastern Australasia region regio nova*

**Etymology:** Designation based upon largest area.

**Stratigraphic range:** Late Devonian.

**Type:** MacDonnell Ranges, Amadeus Basin, Central Australia.

**Diagnosis:** Freshwater and brackish assemblages, including tetrapodomorpha, the antiarch *Bothriolepis*, osteolepiform *Marsdenichthys longioccipitus* (Long, 1986) and the placoderm *Placolepis*, which is endemic to Eastern Gondwana, observed between North Eastern Queensland, central western NSW and the Transantarctic Mountains, Antarctica (Johanson and Young, 1999; Young, 2005; Holland, 2010). Gastropod fauna include abundant bellerophontids in the Canning Basin, genera including *Aglaoglypta*, *Plagiothyra*, *Pseudomphalotrochus* indicating North American and European affinities (Cook, 2001).

**Remarks:** Eastern Gondwanan reefs collapsed in the Late Devonian ending the Tasman region (Webb, 1988). Some vertebrate taxa, such as *Bothriolepis*, survived into the Late Devonian (Johanson, 1998) when a more broadly dispersed vertebrate fauna typified Eastern Australasia. There is evidence of connection between the Eastern Australasia, Mardoowarra and Rhenish-Bohemian regions (Webb, 1988).

#### *New Zealand region*

New Zealand subprovince Boucot et al. 1969

New Zealand region Boucot and Gray, 1979  
New Zealand region Bigey, 1985

**Stratigraphic range:** Early Devonian.

**Type:** Reefton group, New Zealand (South Island).

**Diagnosis:** A mixture of Tasman (*Maoristrophia* and *Reeftonia*), Malvinokaffric (*Pleurothyrella* and *Tanerhynchia*) and endemic (*Allanetes* and *Reeftonella*) brachiopod elements (Boucot et al., 1969). Found only within the Reefton Group and Baton Formation, West Coast, South Island, New Zealand (Boucot et al., 1969). Units termination is based upon the temporal range of definitive taxa, such as *Pleurothyrella venusta*.

**Remarks:** The Devonian deposits within New Zealand are depauperate resulting in insufficient data to discern trends of Early Devonian (Bradshaw, 1999; R.A. Cooper pers. comm. 2016). Devonian New Zealand bares the hallmarks of shelf and shallow-water deposition, with reefs, stromatoporoids and bioherms observed and, in some formations, within an alternating sequence of thicker shelf mudstone (Fagerstrom and Bradshaw, 2002). The base of the Baton formation marks an abrupt increase in water depth with a change from arenaceous shelf sedimentation to deeper water, fine-grained lithologies (Bradshaw, 2000). The Baton fauna, from the Baton River series of seven members have been described as having Bohemian affinity, secondary to the Tasman region from which it split in the Early Devonian (Allan 1947; Plusquellec, 2015; Dowding and Ebach, 2016). It is possible that the New Zealand region is nested within that of the Tasman as both subprovinces within New Zealand (Baton and Reefton) exhibit strong relationships to the Melbourne zone of Australia's southeast (Dowding and Ebach, 2016). For instance, the unit is described as a transitional area between realms (the Malvinokaffric and Tasman region of the Old World, Shirley, 1938, Boucot et al., 1963), but its delineation is based upon a relatively depauperate fauna (Boucot et al., 1969; Boucot 1974). The Reefton Group falls within the Buller terrane and consists of 10 formations and five inliers of Emsian/Early-Middle Devonian age, the majority of which have been cited as presenting strong resemblance and shared association to Australia (Fagerstrom and Bradshaw, 2002; Wright, 1990; Pedder et al., 1970; Scott, 2013).

**Subprovinces included:** Reefton (Buller) subprovince (Dowding and Ebach, 2016).

#### *Rhenish-Bohemian region*

Rhenish-Bohemian subprovince Boucot et al., 1969  
Rhenish-Bohemian region Boucot 1974

**Stratigraphic range:** Early Devonian to Frasnian (Meyerhoff et al., 1996)

**Type:** Prague Basin, Czech Republic.

**Diagnosis:** Characterised by warm-water brachiopods *Athyris*, *Tropidoleptus*, *Pustulatia*, *Trematospira*, *Protoleptostrophia* and meristellids and the trilobite *Greenops* (Boucot, 1974).

**Distribution:** Europe from the western margins of the Russian platform, West and North Africa from Guinea north, Arabia and coastal Acadian parts of eastern North America including the Annapolis Valley of Nova Scotia, plus the coastal Maine and New Brunswick. Armorican Massif is notable for having Eastern American affinities within the Emsian (Boucot and Blodgett, 2001). The region shared a border with the Appohimchi subprovince (Boucot, 1974) and a boundary with the Eastern Americas realm near the St. Lawrence River in southwestern Nova Scotia from New Brunswick to Northeastern Mexico.

**Remarks:** Though initially identified by brachiopods, the Rhenish-Bohemian province has been subsequently identified using gastropods, rugose, corals, trilobites (Oliver and Pedder, 1989; Boucot, 1974). This warm-water region was derived from the Silurian Uralian-Cordilleran region and European province and had low energy reef environments with black shale facies surrounded by pelagic communities (Boucot, 1974).

**Subprovinces included:** Subprovinces do exist for this region, but are unrelated to those of Boucot. See Afanasieva and Amon, 2013

#### *North Africa province*

North African province Oliver, 1977

**Stratigraphic range:** Early to Late Devonian.

**Type:** Rich Formation, Morocco.

**Diagnosis:** Characterised by braided fluvial and arch-basin systems upon the passive Gondwanan margin and a significant Silurian holdover (Carr, 2002; Lamotte et al. 2013). Distributed across North Africa, bound to the east and south by terrestrial environments and the Malvinokaffric (Boucot, 1974, 1988; Oliver, 1977.).

**Remarks:** The Silurian holdover present within the province included Bohemian elements that lasted throughout the Givetian (Boucot, 1988). The province became more cosmopolitan during the late Early Devonian correlated with the tectonic action of the Variscan (Hercynian) orogeny (Oliver, 1976; Carr, 2002; Lamotte et al. 2013). In association with the convergence of the Euramerican and Gondwanan continents, Eastern Americas realm rugose corals appeared within Africa, migrating either through breaks in the peninsula or through its southern edge (Oliver, 1976).

#### *Tasman region*

Tasman subprovince Boucot et al. 1969

Tasman region Cocks and McKerrow, 1973  
Tasman region Plusquellec, 2015

**Range:** Lochkovian to Frasnian.

**Type:** Garra Formation, Australia.

**Diagnosis:** Equatorial fauna of four brachiopod communities, generally within turbulent benthic level bottom communities (Boucot, 1974). Australia and New Zealand (Baton subprovince; Dowding and Ebach, 2016). Expands in the Middle Devonian to include New Zealand and eastern Antarctica.

**Remarks:** The region was distributed across eastern Australia from northern Queensland with the addition of New Zealand's northwestern Nelson (Boucot and Blodgett 2001). The region was geologically active with the eastern Gondwanan margin convergent within a back-arc setting and alternative extensional and contraction phases (Von Raumer et al., 2002; Fergusson, 2010; Boger, 2011). Following along the continental margin, the region encompasses myriad facies including low and high energy substrates, volcanoclastics, shallow marine and patch reefs complete with reef mounds and some megaturbidites forming within the forearc basin, freshwater, brackish, estuarine and fluvial deposition (Bradshaw, 2000; Talent et al., 2000; Fagerstrom and Bradshaw, 2002). Environmental variation facilitated the identification of multiple provinces and subprovinces within the region.

#### *East Australia province*

*Wuttagoonaspis-Phyllolepid* province Young, 1981

**Stratigraphic range:** Emsian to Eifelian.

**Type:** Mulga Downs Group, western New South Wales.

**Diagnosis:** Based upon the presence of the placoderm, *Wuttagoonaspis* in association with some crossopterygii, acanthodians and thelodonts (Young, 1981). Distributed across central Australia (Young, 1981; Neef and Larsen, 2003).

**Remarks:** East Australia province has significant terrestrial and freshwater influence. The province was terminated with the Tasman region by the end of the Middle Devonian and was succeeded by the Eastern Australasia region.

#### *Mardoowarra region nova regio*

**Etymology:** Nyikina First Peoples for The Fitzroy River, Kimberly region within which the Canning Basin is located.

**Stratigraphic range:** Early to Late Devonian.

**Type:** Virgin Hill Formation, Canning Basin, North Western Australia.

**Diagnosis:** Characterised by warm-water trilobite and ammonite assemblages (McNamara and Feist, 2008; McNamara et al., 2009). Endemic taxa include *Gondwanapis spinosa* and *Globoharpes*; the presence of *Eskoharpes* indicating a strong

Rhenish-Bohemian influence (McNamara et al., 2009). The region is distributed across north western Australasia through to Antarctica and India in shelf and reef to pelagic environments.

**Remarks:** The region shows considerable faunal exchange with the Old World, ammonite fauna such as *Manticoceras* found also in Euramerican and the Ural region (Day, 1988; McNamara et al., 2009). The presence of the brachiopod *Tenticospirifer columnaris* in northwestern Australia (Roberts et al., 1972) is indicative of a biogeographic relationship with Western Laurussia (Ma and Day, 2000). The region terminates in the Late Devonian and is annexed by the Western Gondwana realm.

#### *South China region*

South China province Young, 1981

South China region Boucot and Gray, 1979

South China region Boucot and Blogett, 2001

**Stratigraphic range:** Devonian.

**Type:** Hexian Formation, Guangxi Zhuang Autonomous Region, China.

**Diagnosis:** Highly endemic in the Early Devonian, the equatorial unit has a strong freshwater influence and is characterised by galeaspid and polybranchiaspid agnathans and placoderms yunnanolepid antiarch and quasipetalichthyids (Young, 1981; Young et al., 2010). The unit included China south of the Tsin Ling Fold Belt (Young, 1981), northern Vietnam, Western Kunlun, Tarim and the Pan-Cathaysian area (Boucot and Blodgett 2001; Chen, 2004; Zhao and Zhu, 2010). The region, despite increasing external influence, maintained a strong endemic element until the end of the Devonian (Young, 2006; Young et al., 2010 and Zhao and Zhu, 2010).

**Remarks:** The associations of the south China region have come under much scrutiny, in part, due to the controversies surrounding its Devonian location (Oliver, 1977; Young et al., 2010). The documented relationships of the South China region include the Urals, Russian Platform, North China, Australia and Saudi Arabia (Boucot and Blodgett, 2001; Zhao and Zhu, 2010; Chen, 2004; Young et al., 2010). The relationship with Australia has proven of specific interest due to the potential for the South China region and associated blocks to act as a 'stepping stone' between Gondwana and Laurussia via Kazakhstan during the Givetian through to the Late Devonian (Li et al., 1993; Young, 2006, Zhao and Zhu, 2010). Increasing faunal exchange with Asia during the Devonian may have been initiated with Pragian-Emsian faunal turnovers in the South Chinese assemblages, with the Tarim Block withdrawing throughout the Late Devonian and into the Carboniferous (Young and Janvier, 1999; Young et al., 2010; Chen, 2004). The 'stepping stone' model presents itself as an alternative to distance dispersal between the Chinese blocks or the proposed Early/Middle Devonian closure of the ocean

between Western Gondwana and Laurussia (Young, 2006) though the theory is unsupported by Blicek et al., (2002).

Young et al., (2010) used the regions biogeography to comment on the area's geological relationships, stating that the hypothesis of Metcalfe (1996) and Zhao et al., (1996) that the China blocks and associated terranes originated from the Northern Gondwanan margin were contradicted by the placoderm data.

#### *Junggar-Xinan province*

Junggar-Xinan province Hou, 1981

**Stratigraphic range:** Devonian.

**Type:** Mongkelu Formation, Xinjiang, China.

**Diagnosis:** Abundant benthos, scarce nektonic organisms within a platform setting, with European and North American brachiopod affinities (Hou, 1981). Geosynclinal setting with volcanics and clastics. Characteristic taxa include the brachiopods *Leptostrophia*, *Rhytistrophia*, *Gladistrophia*, *Megastrophia*, *Leptaenopyxis* amongst others in three assemblages (see Hou 1981). The unit lies between the Sino-Korean and Tungrian landmasses, including eastern and western Junggar in Xinjiang, the Northern Tianshan Mountains, Inner Mongolia, northern northeast China, the Beishan Mountains, east to the Okhotsk Sea, west to the Balkash Lake (Hou, 1981).

**Remarks:** The brachiopod assemblages make the province unique intermediate between the Old World and Eastern Americas realms. Middle Devonian brachiopods relatively unknown, represented by Early Devonian holdovers. Some Middle Devonian correlation with the North American Hamilton and Onondaga formation; Appalachian province affinities shown through mutual absence of Old World stringocephalids.

#### *South China province*

South China province Hou, 1981

Galeaspid-yunnanolepid Young, 1981

**Stratigraphic range:** Devonian.

**Type:** Putonggou Formation in the Diebu area, West Qinling, China.

**Diagnosis:** The benthic platform fauna were highly endemic including the brachiopods *Orientospirifer*, *Aeptalium* and *Kwangsirhynchia*. The *Karpinskia-Spirigerina* assemblage bore Ural and European influence. Platform sediments. The unit was distributed across southern regions of China, the eastern extension of the Ural-Tianshan Marine belt and the South Tianshan Mountains (Hou, 1981). The vertebrate assemblage was defined by the presence of the endemic galeaspid and polybranchiaspid agnathans in association with gnathostome placoderms yunnanlepid antiarchs and quastipetalichthyids to the exclusion of holonematids and coccosteids characteristic of

China in other regions (Young, 1981). Continental South China type is based upon galeaspid distribution (Zhu, 2000).

**Remarks:** South China and Junggar-Xinan provinces separated by the Tarim and Sino-Korean landmasses. The province underwent Early Devonian tectonic events resulting in increased provincialism. During the Late Devonian cosmopolitan fauna appeared in the province in particular the brachiopod *Eoperegrinella baschkirica*, a genus identified in Poland, North America, North Africa and the Urals (Huo, 1981).

South China, during the Devonian, was located north of the palaeoequator. This province presents an highly endemic vertebrate fauna with the migration of cosmopolitan taxa observed within the region by Middle Devonian time, though the province retained its endemic characters into the Late Devonian.

**Subprovinces included:** South Tianshan, Southwestern and South subprovinces (Hou, 1981).

#### *Uralian Region*

Uralian subprovince Boucot et al., 1969

Uralian region Boucot, 1974

**Stratigraphic range:** Devonian.

**Type:** Pai Hoi and Vaigatsch in the Urals and the Solovien limestone, Altai Mountains.

**Diagnosis:** Characteristic brachiopod forms include *Sibirihynchia*, *Janius*, *Karpinskia*, *Ivdelina* and endemic uncinuloids and gypiguloids. Abundance of brachiopods distinguishes this region from the Cordilleran, which is comparatively depauperate (Boucot et al., 1969). Brackish to non-marine deposition. The unit includes the east and west Urals, Siberia including Taimyr, Kolyma, Chukotka, Kuznetsk Basin. Tien Shan, southeastern Kazakhstan, plus the Farewell, Alexander and Arcto Alaska Terranes.

**Remarks:** The region was descendent from the Silurian Uralian-Cordilleran region (Boucot, 1974).

#### *Balkash-Mongolo-Okhotsk province*

Balkash-Mongolia-Okhotsk region Hou and Boucot, 1990

Balkash-Mongolo-Okhotsk province Boucot and Blodgett, 2001

Junggar-Mongolo-Okhotsk region Wang et al., 2013

**Stratigraphic range:** Early Devonian.

**Type:** Great Khingan Range, China.

**Diagnosis:** Characterised by the brachiopod fauna *Acrospirifer*, *Areostrophia*, *Aulacella*, *Brachyspirifer*, *Coelospira*, *Dalejina*, *Megastrophia*, *Paraspirifer* and *Protochonetes* (Wang et al., 2013). Endemic fauna punctuated by Tasman and Eastern American elements (Boucot and Blodgett, 2001). The unit is inclusive of Lake Balkhash of



southeastern Kazakhstan, Mongolia, Neimonggol and the Greater Khingan Mountains in Heilongjiang (Boucot and Blodgett, 2001; Wang et al. 2013).

**Remarks:** The history and provinces of this region are confused somewhat by inconsistency of area nomenclature. Competing interpretations by Hamada (1971), Hou (1981), Hou and Boucot (1990) and Boucot and Blodgett (2001) are resolved within Wang et al., (2013). Wang et al., (2013) assigned the Altai-Sayan and Junggar-Balkhash provinces of Hamada (1971) (now subprovinces) to the Balkash-Mongolo-Okhotsk region, arguing towards joining Balkash-Mongolo-Okhotsk and Junggar-Mongolo-Okhotsk as a single province. To solve these inconsistencies the Balkash-Mongolo-Okhotsk is reassigned to province within the Uralian Region, consistent with the characterisation of Lindsey-Griffin et al., 2008

**Subprovinces included:** Balkash-Mongolo-Okhotsk subprovince, Junggar-Balkhash subprovince (Hamada, 1971), Altai-Sayan subprovince (Hou and Boucot, 1990).

#### *Siberian province*

Amphiaspid (Siberia) province Young, 1981

Siberian region Lebedev and Zakharenko, 2010

Siberia province Afanasieva and Amon, 2013

**Stratigraphic range:** Early Devonian to middle Frasnian.

**Type:** Timan-Pechora basins, Timan Range and the Ural Mountains in northern Russia. For vertebrate fauna, the Bel'kovsky-Nerpalakh trough, Russia (Kos'ko and Korago, 2009).

**Diagnosis:** Young (1981) characterised the province by amphiaspid heterostracans and *Gerronaspis*, in association with acanthodians, porolepid rhipidistians, palaeoniscoids and placoderms. The area is spread across the Siberian platform, and gulf with potential salinity barriers inclusive. The diagnosis of Afanasieva and Amon (2013) is based upon endemic radiolarians. Typically, clayey carbonate strata with relatively depauperate marine fossils.

**Remarks:** A marine transgression initiated in the late Middle Devonian reached a maximum in the Frasnian reducing the size of the continental assemblages, with Givetian fauna poorly known (Lebedev and Zakharenk, 2010). The endemic osteostracan *Ilemoraspis* characterises the area's vertebrate fauna (Lebedev and Zakharenk, 2010). The heterostraci are represented by *Putoranaspis* and *Aphatapsis* (Halstead, 1973).

Transport between the three main Chinese blocks (Tarim, South China and North China), Siberia and Euramerica was present in the Early Devonian, facilitated by the southern Circum-Panthalassic ocean route or the northern route through Kazakhstan (Young 2005; Zhao and Zhu, 2010), though this theory is unsupported by Blicek et al. (2002). Lower Devonian biogeographic links based on brachiopods, suggest that the southwest Alaskan Farewell terrane represented a

rifted continental margin sequence from the Siberian continent (Blodgett et al., 2002).

Though the province maintained an endemic element throughout the Late Devonian, the radiolarian assemblages in particular reflect increased migration from Euramerican, Ural and Australian provinces (Blodgett and Boucot 1999; Boucot and Blodgett, 2001; Afansieva and Amon, 2013). The Amphiaspid province of Young (1981) was, however, limited to the region west of the Tuvan Massif. The area was characterised by platforms seagulfs of varying salinity, with infrequent, clayey carbonate strata. The province provides evidence of significant Middle Devonian migration from the Australian province.

**Subprovinces included:** Rudny Altai subprovince, Western Siberia subprovince (Afanasieva and Amon, 2013).

#### *Ural-southern Tianshan province*

Ural-southern Tianshan province Hamada, 1971

Ural-southern Tianshan province Huo and Boucot, 1990

Ural-southern Tianshan province Wang et al., 2013

**Stratigraphic range:** Devonian.

**Type:** Gorny Altai, Siberia.

**Diagnosis:** Characteristic fauna includes the brachiopods *Glossinulus* (*Glossinotoechia*), *Karpinskia* and *Nikiforovaena* (Wang et al., 2013). Distributed across Central Asia from Chelyabinsk to Khabarovsk and Northern Mongolia (Wang et al., 2013). Serov, Belaja River, Kuznetsk Basin, Gorny Altai, Mongolian Altai and Tarim.

**Remarks:** In the Early Devonian, the western margin of the Kazakhstan plate, eastern Siberian plate and northern Eastern European plate formed the Ural-Tianshan Ocean and tectonic region. The area presents strong Ural affinities, especially within the Altai-Sayan subprovince (Wang et al., 2013). Significantly, the province also showcases many Balkhash-Mongolo-Okhotsk elements, this is potentially due to the analogous tectonic events within the areas. The relationship was maintained throughout the Late Devonian during the processes of accretion and collision along the Hercynian fold belt and the Ob-Zaisan folded system (Dobretsov and Kirkdysahkin, 1994; Wang et al., 2013). Area possibly subsumed as a subprovince of the South China province (Hou, 1981).

#### *Tuva province*

Tannuaspid (Tuva) province Young, 1981

**Stratigraphic range:** Early Devonian.

**Type:** Chondergeyskaya, Samagaltayskaya and Kendeyskaya Group of the Tuvin depression in southwestern Tuva (Afanasieva and Janvier, 1985).

**Diagnosis:** Endemic Siluro-Devonian ostracoderms including osteostracan *Tannuaspis* and *Tuvaspis*. Distributed across the Tuva Massif, Tuva-Minusinsk-Kusnetsk region.

**Remarks:** The Tunnaspid province extends through the Tuva-Minusinsk-Kusnetsk region located on the eastern side of the Siberian continent (Young, 1981). The province had some faunal exchange with the Euramerican province (Young, 1981).

#### *Western Gondwana realm nova regio*

**Etymology:** Designation based upon largest area.

**Stratigraphic range:** Late Devonian.

**Type:** Parnaiba Basin, Brazil.

**Diagnosis:** Cold-water, Appalachia, South America, South Africa and Antarctica south of Victoria Land. Depositional trend that is strongly controlled by fluvial input into a shallow marine environment (Ponciano and Della Favera, 2009) bearing gastropods (*Bucanella dereimsi*), trilobites (*Burmeisteria*, *Rhenops*), bivalves (*Modiomorpha* cf. *M. concentrica*, *Nuculites* cf. *N. africanus*), brachiopods (*Notiochonetes* sp., *Pleurochonetes Pustulatia* sp., *Schuchertella* sp.) and *Spongiophyton* (Wood, 1995; Lieberman and Kloc, 1997; Ponciano and Della Favera, 2009; Leme et al., 2013).

**Remarks:** The realm had mixed Eastern Americas realm and Malvinokaffric realm influences with significant holdovers from the annexed realms (Wood, 1995). The aforementioned realms suffered a collapse of their shelly fauna, the general basis for their characterisation (Boucot et al., 1969), in the late Middle Devonian (Bosetti et al., 2011). Antiarch fauna maintained their presence within the region throughout the Late Devonian (Wood, 1995).

#### Extinction events

##### Zlihov event (early Emsian)

**Distribution:** Europe, associated with an early Emsian, transgressive event recognised in Australia, Siberia and Prague basin (Talent and Yolkin, 1987; House and Kerr, 1989; Grahn and Paris, 2011).

**Diagnosis:** The Zlihov event is characterised by the loss of the mimosphinctid and auguritid ammonoids (House and Kerr, 1989) and associated with high chitzoan abundance but low diversity (Grahn and Paris, 2011).

**Discussion:** The Zlihov event is associated with gradual oceanic deepening and deposition of black, calcareous shale facies with a subsequent regression at the base of the Pragian (House and Kerr, 1989). The observation of pyritic preservation is indicative of anoxia with consequent suggestion of ocean overturning as a mechanism for the spread of anoxic waters across oceanic shelves (House and Kerr, 1989).

##### Chotec event (early Eifelian)

**Distribution:** Czech Republic, Morocco, Eifel Hills, Rhenish Slate Mountains, Armorican Massif, Cantabrian Mountains, Eastern Iberian Chains, Portugal, Siberia, Ural and the Appalachian Basin (Vodrazkova et al., 2013).

**Diagnosis:** Trilobites, such as coarsely sculpted and large species of the phacopidae, became extinct during this interval (McKellar, 2006). Within the Hercynian facies, the deposition of the black shales is contemporaneous with the appearance of the ammonoid *Pinacites jugler*, and in the Rhenish the disappearance of the brachiopod *Alatiformia alatiformis* (Ernst et al., 2012).

**Discussion:** Linked and considered to overlap with the Taghanic event in Morocco, the event is associated with marine lowstand and shallow-water carbonate production followed by transgressive series and the deposition of black shales (McKellar, 2006). Oxygen consumption through the degradation of newly heightened nutrient availability is believed to have led to the extinction and/or migration of benthic taxa (Vodrazkova et al., 2013).

##### Daleje event (middle Emsian)

**Distribution:** Barrandian Basin, Prague Basin.

**Diagnosis:** Local extinctions, specifically the elimination of the dalmanitid trilobites eliminated from the Prague Basin in association with shale sedimentation (Budil et al., 2009).

**Discussion:** Associated with eustatic sea level rise and subsequent deposition of sharp rise in tetaculite-rich shales across the Old World Faunal realms, minor faunal impacts (House and Kerr, 1989). Within the Barrandian Basin, the Koneprusy reef complex was partially surfaced and eroded at the Zlichovian-Dalajan boundary (Suchý et al. 2012). Eustatic sea level rise, localised extinction (Old world realm; Prague Basin) (House and Kerr, 1989; Budil et al., 2009).

##### Middle Devonian biocrisis (late Eifelian–Givetian)

**Distribution:** Predominantly limited to the Laurussia (Old red continent). Depositions found in the Prague Basin, Germany, Southwest England, Scotland, Southern France and Northern Spain. Evidence outside of the Old Red Continent comes from Morocco, New York State Northern America, South China and, Australia (House, 1996; House and Kerr, 1989; DeSantis and Brett, 2011; Jurina and Raskatova, 2011).

**Diagnosis:** The Middle Devonian (late Eifelian) biocrisis is an interval that can be separated into three distinct events, being the Bakoven, Stony Hollow and ultimately the Kacak event in the *ensensis* conodont zone (DeSantis and Brett, 2011). Correlation between the Kacak member recognises the event within *hemiansatus* Zone, the upper *kockelianus* Zone and the overlying Roblin member, including regions in Scotland and

Estonia (Jurina and Raskatova, 2011; Mark-Kurik and Poldvere, 2012).

**Discussion:** The Bakoven event, named after the and found within the *Bakoven australis* to *eiflius* zones within the Appalachian Basin and contemporaneous northern America, is marked by a loss of species diversity, eustatic deepening and hypoxia (DeSantis and Brett 2011).

Stony Hollow event (*kockelianus*–*eifelis* zone) saw the incursion of tropical old world, Cordilleran province taxa into the sub-tropical to temperate shelf region of eastern North America (DeSantis and Brett, 2011). The primary signature of the Stony Hollow (late Eifelian) incursion was an abrupt expansion of OWR Cordilleran province taxa into eastern North America. The immigration records a major expansion of biogeographic boundaries, as most of the taxa, or closely-related forms, remained in the Old World realm Cordilleran region throughout and after the Stony Hollow interval (DeSantis and Brett, 2011).

The Kacak event is recognised in conodonts and dacroconarids and ammonoids (House, 1996; DeSantis and Brett, 2011). Identified by hypoxic or anoxic shales and limestones coupled with eustatic sea level rise (House, 1996) has been estimated to have lasted between 200,000 and 700,000 years in various locations (House and Kerr, 1989; Ellwood et al., 2011). The Kacak event is associated with geochemical anomalies in nickel, carbon and oxygen isotopes and Total Organic Carbon (TOC) as well as changes in lithoferric constituents identified by excursions in magnetic susceptibility (House and Kerr, 1989; House, 1996). Large eustatic sea level rise and widespread anoxia produced a downturn in trilobite diversity including minor effects within the phacopids (McKellar, 2006).

#### Taghanic (late Givetian)

**Distribution:** Hamilton Fauna Northern Appalachian Basin, North American Basin (Laurentia), Morocco, Moscow Russia, Ardennes, Rheinisches Schiefergebirge, Prague Basin, Morvarian Karst (McKellar, 2006; Baird and Brett, 2008).

**Diagnosis:** Regionally, clear carbonate deposition transitions to increasingly anoxic black muds and limestones with pelagic faunal incursions into sheltered basins (Baird 2008). The alteration of habitat, highstand and associated invasion lead to the major faunal fluctuations; notable extinctions include the *Sobolewia* (Sobolweiidae), with genera of ammonoids, goniatites, corals and brachiopods all substantially effected (House and Kerr, 1989).

**Discussion:** The Taghanic bioevent describes a ~500,000 year cumulative series consisting of four events equally split into the Lower Tully and Taghanic events that may have been as severe as the Frasnian-Famennian extinction (House and Kerr, 1989; Aboussalam and Becker, 2011; Baird and Brett, 2008; McKellar, 2006). The Taghanic bioevents were preceded by a 4–5-Ma interval of relative stability, both ecological and evolutionary, during the majority of the early and middle Givetian (Baird

and Brett, 2008). The Taghanic bioevent was set during the second and third collisional tectophases of the Acadian Orogeny (Baird, 2008; Zambito, 2011). Global increases in aridity, temperature were coupled with marine highstand, rapid eustatic sea level fluctuations decreased oxygenation of epicontinental seas and extreme marine highstand (Marshall et al., 2011).

#### Kellwasser crisis (late Frasnian)

**Distribution:** Related epicontinental and basinal facies have been identified in Gondwana, Siberia, South China and Laurussia (Carmichael et al., 2014), suggests global event (Waters et al., 2013).

**Diagnosis:** The Kellwasser extinction of 13–40% of all families and 50–60% of genera, with only minor vertebrate fauna loss (Sole and Newman, 2002; Sallan et al. 2010).

**Discussion:** It is limited by two bands of anoxic shale, which may in turn suggest two distinct extinction events, and was preceded by an extended period of biodiversity loss (Sole and Newman, 2002; Balter et al., 2008). Protracted nature of the Kellwasser event is supported by trilobite adaptive morphologies, small eyes and wide respiratory brims an adaptation to the high turbidity and low oxygenation associated with the event (Balter et al. 2008). Exclusively marine, shallow warm-water taxa, including vertebrates such as antiarchs, jawless fish and placoderms, suffered 65% extinction (Bambach, 2006; Sallan et al. 2010). The protracted nature and similarity of the Kellwasser and Hangenberg events often see some of the extinctions of the Kellwasser attributed to the later Hangenberg event, due to the poor Famennian fossil record (Algeo et al., 1998). The extinction is thought to have two pulses, the first regressive phase lasting 400 kyr and the second transgressive leasing 50 kyr (Chen and Tucker, 2003).

#### Hangenberg event (Famennian)

**Distribution:** Gondwana, Siberia, Laurussia, South China, indicative of a global event (Waters et al., 2013).

**Diagnosis:** Widespread anoxia in oceanic bottom waters, increased carbon deposition, and the continued reduction and depletion of shallow warm-water taxa and habitat (Algeo et al., 1998). Overall extinction peaked at 31% with stromatoporoids, rhynchonellid brachiopods, ammonoids, trilobites, placoderms and osteichthyes suffering rates of 70% (Bambach, 2006). The extinction of terrestrial taxa, up to 40% of vertebrates, have been set as a precursor to the Carboniferous Romer's gap (Sole and Newman, 2002; Ward et al., 2006; Sallan et al., 2010).

**Discussion:** The cause of the Hangenberg event remains contentious. Forest fires, soil erosion, glacial events and eutrophication have all been cited as potential causes of the Late Devonian extinction events (Algeo et al., 1998; Murphy et al. 2000; Racki et al., 2002; Tribovillard et al., 2004; Bambach, 2006; Kazmierczak et al., 2012; Kaiho et al., 2013; Carmichael et al.,

2014), but discussions are focussed primarily upon transgressive and regressive cycles and, tectonic action (Sandberg et al., 1988; Joachimski and Buggisch, 1993; McGhee, 1991; Chen et al., 2002; Bond et al., 2004; Tribovillard et al., 2004; Bond and Wignall, 2008; Chen et al., 2013).

Causal links between the evolution of increased arborescence and seed habit and the extinction through the rapid decrease of atmospheric CO<sub>2</sub> from 4000 ppm to nearly present-day values of about 350 ppm during the latest Devonian (Royer 2006 in Carmichael et al., 2014). These interactions between primary and secondary causes, such as tectonic movement, atmospheric eutrophication, could have coincided to bring about the Late Devonian extinctions (Algeo et al., 1998; Carmichael et al., 2014).

## Conclusions

The work of Boucot has formed a solid foundation for past and present Devonian bioregionalisations. This study has reviewed the global bioregionalisations under stringent conditions to provide a standardised diagnosis of Devonian biogeographical units within a formalised hierarchy. The establishment of three new areas provides the Devonian with its first complete bioregionalisation. Though both authors acknowledge the limitations and problematic description of a cosmopolitan Old World realm in the Late Devonian, no viable alternative has been offered under Boucot's framework. This review instead amended the failure to assign areas, completed the bioregionalisation and will now act as a hypothesis for any future empirical tests of Devonian bioregionalisation. Until then, this interim bioregionalisation and review will offer a template for future studies.

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## Compliance with ethical standards

**Conflict of interest:** The authors declare that they have no conflict of interest.

## References

- Afanasieva, M. S., & Amon, E. O. (2013). Paleobiogeographical radiolarian provinces in the Devonian. *Paleontological Journal*, 47(10), 1135–1154.
- Afanasieva, O., & Janvier, P. (1985). *Tannuaspis*, *Tuvaspis*, and *Ilemoraspis*, endemic osteostracan genera from the Silurian and Devonian of Tuva and Khakassia (USSR). *Geobios*, 18(4), 494–406.
- Albert, J. S., & Reis, R. E. (2011). *Historical biogeography of neotropical freshwater fishes*. California: University of California press.
- Algeo, T. J., Scheckler, S. E., & Scott, A. C. (1998). Terrestrial-marine teleconnections in the Devonian: links between the evolution of land plants, weathering processes, and marine anoxic events. *Philosophical Transactions: Biological Sciences*, 353(1365), 113–130.
- Allan, R. S. (1947). A revision of the Brachiopoda of the Lower Devonian strata of Reefton, New Zealand. *Journal of Paleontology*, 21(5), 436–452.
- Amsden, T. W., Klapper, G., & Ormiston, A. R. (1968). The Lower Devonian limestone of Post-Hunton Age, Turkey Creek Inlier, Marshal County, South Central Oklahoma: notes. *The American Association of Petroleum Geologists Bulletin*, 51(1), 162–171.
- Anderson, M. E., Long, J., Evans, F. J., Almond, J. E., Theron, J. T., & Bender, P. A. (1999). Biogeographic affinities of Middle and Late Devonian fishes of South Africa. *Records of the Western Australian Museum*, 57, 157–168.
- Arltdt, T. (1907). *Die Entwicklung der Kontinente und ihrer Lebewelt: ein Beitrag zur vergleichenden Erdgeschichte*. Leipzig: W. Engelmann.
- Arltdt, T. (1912). *Die fauna der alten tierregionen des Festlandes*. Stuttgart: F. Schweizerbartsche Verlagsbuchhandlung Nägele & Dr. Sproesser.
- Arltdt, T. (1919–1921). *Handbuch der Palaeogeographie*. Stuttgart: Gebrüder Borntraeger Verlagsbuchhandlung.
- Baird, G. C., & Brett, C. E. (2008). Late Givetian Taghanic bioevents in New York State: new discoveries and questions. *Bulletin of Geosciences*, 84(4), 357–370.
- Balter, V., Renaud, S., Girard, C., & Joachimski, M. M. (2008). Record of climate-driven morphological changes in 376 Ma Devonian fossils. *Geology*, 36, 907–910.
- Bambach, R. K. (2006). Phanerozoic biodiversity mass extinctions. *Annual Review Earth Planet Science*, 34, 127–155.
- Becker-Kerber, B., Oses, G. L., Curado, J. F., Almeida, R., De, M., Rudnitzki, I. D., Romero, G. F., Onary-Alves, S. Y., Benini, V. G., Galante, D., Rodrigues, F., Buck, P. V., Rangel, E. C., Ghilardi, R. P., & Pacheco, M. L. A. F. (2017). Geobiological and diagenetic insights from Malvinokaffric Devonian biota (Chapada Group, Parana Basin, Brazil): palaeobiological and palaeoenvironmental implications. *PALAIOS*, 32(4), 238–249.
- Berry, W. B. N., & Boucot, A. J. (1970). *Correlation of the North American Silurian rocks*. Boulder, Colorado: Geological Society of America.
- Berry, C. M., Morel, E., Mojica, J., & Villarroel, C. (2000). Devonian plants from Colombia, with discussion of their geological and palaeogeographical context. *Geological Magazine*, 137(3), 257–268.
- Bigey, F. P. (1985). Biogeography of Devonian Bryozoa. In C. Nielsen & G. P. Larwood (Eds.), *Bryozoa: Ordovician to recent* (pp. 9–23). Fredensborg: Olsen and Olsen.
- Blakey, R. C. (2008). Pennsylvanian–Jurassic sedimentary basins of the Colorado Plateau and Southern Rocky Mountains. In A. D. Mail (Ed.), *The sedimentary basins of the United States and Canada* (pp. 245–298). Amsterdam: Elsevier.
- Blicq, A. R. M., Karatajūtė-Talimaa, V. N., & Mark-Kurik, E. (2002). Upper Silurian and Devonian heterostracan pteraspidomorphs (Vertebrata) from Severnaya Zemlya (Russia): a preliminary report with biogeographical implications. *Geodiversitas*, 24(4), 805–820.



- Blodgett, R. B., & Boucot, A. J. (1999). Late early Devonian (late Emsian) eospiriferinid brachiopods from Shellabarger pass, south-central Alaska, and their biogeographic importance; further evidence for a Siberian origin of the farewell and allied Alaskan accreted terranes. *Senckenbergiana Lethaea*, 79(1), 209–221.
- Blodgett, R. B., & Stanley, G. D. (2008). Introduction. In R. B. Blodgett & G. D. Stanley (Eds.), *The terrane puzzle: new perspectives on palaeontology and stratigraphy from the North American Cordillera*. Geological Society of America: Colorado. [https://doi.org/10.1130/2008.442\(00\)](https://doi.org/10.1130/2008.442(00)).
- Blodgett, R. B., Rohr, D. M., & Boucot, A. J. (1990). Early and Middle Devonian gastropod biogeography. *Geological Society London Memoirs*, 12, 277–284.
- Blodgett, R. B., Fryda, J., & Lenz, A. C. (2001). Semitubina yukonensis new species, first occurrence of the biogeographically distinctive old world realm gastropod genus in the lower Devonian of the western hemisphere. *Journal of Paleontology*, 71(2), 466–470.
- Blodgett, R. B., Rohr, D. M. & Boucot, A. J. (2002). Palaeozoic links among some Alaskan accreted terranes and Siberia based on megafossils. In E. L. Miller, A. Grantz and S. L. Klemperer (Ed.) *Tectonic evolution of the Bering Shelf - Chukchi Sea - Arctic Margin and adjacent landmasses*(360, pp.270–290). Colorado: Geological Society of America.
- Boger, S. D. (2011). Antarctica—before and after Gondwana. *Gondwana Research*, 19, 335–371.
- Bond, D. P., & Wignall, P. B. (2008). The role of sea-level change and marine anoxia in the Frasnian-Famennian (Late Devonian) mass extinction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 263, 107–118.
- Bond, D. P., Wignall, P. B., & Racki, G. (2004). Extent and duration of marine anoxia during the Frasnian–Famennian (Late Devonian) mass extinction in Poland, Germany, Austria and France. *Geological Magazine*, 141(2), 173–193.
- Bosetti, E. P., Grahn, Y., Horodyski, R. S., Mauller, P. M., Breuer, P., & Zabini, C. (2011). An earliest Givetian “Lilliput effect” in the Parana Basin, and the collapse of the Malvinokaffric shelly fauna. *Paläontologische Zeitschrift*, 85, 49–65.
- Boucot, A. J. (1974). Silurian and Devonian biogeography. Palaeogeographic provinces and provinciality: based on a symposium sponsored by the Society of Economic Palaeontologists and Mineralogists. C. A. Ross. Tulsa Oklahoma, *Society of Economic Palaeontologists and Mineralogists*, 165–176.
- Boucot, A. J. (1984). Old World realm (Rhenish-Bohemian Region), shallow-water, Early Devonian brachiopods from the Jauf Formation of Saudi Arabia. *Journal of Paleontology*, 58(5), 1196–1202.
- Boucot, A. J. (1985). Late Silurian-Early Devonian biogeography, provincialism, evolution and extinction [and discussion]. *Philosophical Transactions of the Royal Society London B*, 309(1138), 323–339.
- Boucot, A. J. (1988). Devonian biogeography: an update. *Palaeontology, Palaeoecology and Biostratigraphy*, 3, 211–227.
- Boucot, A. J. (1993). Palaeozoic palaeogeography and biogeography. *Revista Espanola de Paleontologia*, 15–20.
- Boucot, A. J., & Blodgett, R. B. (2001). Silurian-Devonian biogeography. In C. H. Brunton, L. R. M. Cocks, & S. L. Long (Eds.), *Brachiopods past and present* (pp. 335–344). London: Taylor and Francis.
- Boucot, A. J., & Gray, J. (1979). A Palaeozoic palaeogeography and biogeography. In J. Gray & A. J. Boucot (Eds.), *Historical biogeography, plate tectonics, and the changing environment* (pp. 465–482). Oregon: Oregon State University Press.
- Boucot, A. J., & Theron, J. T. (2001). First Rhipidothyris (Brachiopoda) from Southern Africa: biostratigraphic paleoecologica. *Journal of the Czech Geological Society*, 46(3–4), 155–160.
- Boucot, A. J., Caster, K. E., Ives, D., & Talent, J. A. (1963). Relationships of a new Lower Devonian terebratuloid (Brachiopoda) from Antarctica. *Bulletin of American Palaeontology*, 46, 81–151.
- Boucot, A. J., Johnson, J. G., & Talent, J. A. (1969). Early Devonian brachiopod zoogeography. *Geological Society of America Special Papers*, 119, 1–60.
- Boucot, A. J., Isaacson, P. E., & Laubacher, G. (1980). An Early Devonian, Eastern Americas realm faunule from the coast of southern Peru. *Journal of Paleontology*, 54(2), 359–365.
- Boucot, A. J., Rowell, A. J., Racheboeuf, P. R., Pereira, E., Goncalves De Melo, J. H., & Peixoto De Siqueira, L. (2001). Position of the Malvinokaffric realm’s northern boundary (Early Devonian) based on newly discovered brachiopods from the Parecis Basin (Brasil). *Journal of the Czech Geological Society*, 46(3–4), 109–120.
- Boucot, A. J., Poole, F. G., Amaya-Martinez, R., Harris, A. G., Sandberg, C. A., & Page, W. R. (2008). Devonian brachiopods of southwesternmost Laurentia: Biogeographic affinities and tectonic significance. *GSA Special Papers*, 442, 77–97.
- Bowman Bailey, J. (1978). Provincialism and migration in lower and middle Devonian pelecypods. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 23, 119–130.
- Bradshaw, M. A. (1999). Lower Devonian bivalves from the Reefton group, New Zealand. *Association of Australasian Palaeontologists*, 20, 1–171.
- Bradshaw, M. A. (2000). Base of the Devonian Baton Formation and the question of a pre-Baton tectonic event in the Takaka Terrane, New Zealand. *New Zealand Journal of Geology and Geophysics*, 43(4), 601–610.
- Budil, P., Horbinger, F., & Mencl, R. (2009). Lower Devonian dalmanitid trilobites of the Prague Basin (Czech Republic). *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 99, 61–100.
- Carmichael, S. K., Waters, J. A., Suttner, T. J., Kido, E., & DeReuil, A. A. (2014). A new model for the Kellwasser anoxia events (Late Devonian): shallow water anoxia in an open oceanic setting in the Central Asian Orogenic Belt. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 399, 394–403.
- Carr, I. D. (2002). Second-order sequence stratigraphy of the Palaeozoic of North Africa. *Journal of Petroleum Geology*, 25(3), 259–280.
- Cecca, F., & Westermann, G. E. G. (2003). Towards a guide to palaeobiogeographic classification. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 201, 179–181.
- Chen, Z.-Q. (2004). Devonian-Carboniferous brachiopod zonation in the Tarim Basin, northwest China: implications for biostratigraphy and biogeography. *Geological Journal*, 39, 431–458.
- Chen, D. Z., & Tucker, M. E. (2003). The Frasnian-Famennian mass extinction: insights from high resolution stratigraphy and cyclostratigraphy in South China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 193, 87–111.
- Chen, D., Tucker, M., Shen, Y., Yans, J., & Preat, A. (2002). Carbon isotope excursions and sea-level change: implications for the Frasnian-Famennian biotic crisis. *Journal of the Geological Society (London)*, 159, 623–626.
- Chen, D. Z., Wang, J. G., Racki, G., Li, H., Wang, C. Y., Ma, X. P., & Whalen, M. T. (2013). Large sulphur isotopic perturbations and oceanic changes during the Frasnian–Famennian transition of the Late Devonian. *Journal of the Geological Society (London)*, 170, 465–476.
- Chlupac, I. (1975). The distribution of phacopid trilobites in space and time. *Fossils and Strata*, 4, 399–408.
- Cocks, L. R. M. (2011). There’s no place like home: Cambrian to Devonian brachiopods critically useful for analysing palaeogeography. *Memoires of the Association of Australasian Palaeontologists*, 41, 135–148.
- Cocks, L. R. M. & McKerrow, W. (1973). Brachiopod distribution and faunal provinces in the Silurian and Lower Devonian. In N. F. Hughes (Ed.) *Organisms and continents through time* (22, pp.291–304). Durham: Palaeontological Association.

- Sallan, L., Coates, M. I., & Clack, J. (2010). End-Devonian extinction and a bottleneck in the early evolution of modern jawed vertebrates. *Proceedings of the National Academy of Sciences of the United States of America*, 107(22), 10131–10135.
- Cook, A. G. (2001). Palaeobiogeography of Australian Devonian gastropods. *Historical Biology: an International Journal of Paleobiology*, 15(1–2), 77–82.
- Copper, P. (1998). Evaluating the Frasnian-Famennian mass extinction: comparing brachiopod faunas. *Acta Palaeontologica Polonica*, 43(2), 137–154.
- Costa, M., Vilorio, A. L., Huber, O., Attal, S., & Orellana, A. (2013). Lepidoptera del Pantepui. Parte I: Endemismo y caracterización biogeográfica. *Entomotropica*, 28, 193–217.
- Day, J. (1988). The brachiopod succession of the Late Givetian-Frasnian of Iowa. In N. J. McMillan, A. F. Embry and D. J. Glass (Eds.) *Devonian of the world* (3, pp.303–325). Calgary: Canadian Society of Petroleum Geologists.
- DeSantis, M. K., & Brett, C. E. (2011). Late Eifelian (Middle Devonian) biocrises: timing and signature of the pre-Kacak Bakoven and Stony Hollow events in eastern North America. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 304, 113–135.
- Dobretsov, N. L., & Kirkydashkin, A. G. (1994). Blueschist belts of Northern Asia and models of subduction-accretion wedge. In R. G. Coleman & E. G. Juvigne (Eds.), *Proceedings of the 29th International Geological Congress: Reconstruction of the Paleo-Asian Ocean* (pp. 99–114). Utrecht: VSP.
- Dowling, E. M., & Ebach, M. C. (2016). The Early Devonian palaeobiogeography of Eastern Australasia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 444, 39–47.
- Ebach, M. C., & Michaux, B. (2017). Establishing a framework for a natural area taxonomy. *Acta Biotheoretica*, 1–11.
- Ebach, M. C., Morrone, J. J., Parenti, L. R., & Vilorio, A. L. (2008). International code of area nomenclature. *Journal of Biogeography*, 35, 1153–1157.
- Ebach, M. C., Gill, A. C., Kwan, A., Ah Yong, S. T., Murphy, D. J., & Cassis, G. (2013). Towards an Australian Bioregionalisation atlas: a provisional area taxonomy of Australia's biogeographical regions. *Zootaxa*, 3619(3), 315–342.
- Ebach, M. C., Murphy, D. J., Gonzalez-Orozco, C. E., & Miller, J. T. (2015). A revised area taxonomy of phyogeographical regions within the Australian Bioregionalisation Atlas. *Phytotaxa*, 208(4), 261–277.
- Edwards, D. (1973). Devonian floras. In A. Hallam (Ed.), *Atlas of palaeobiogeography* (pp. 105–115). New York: Elsevier.
- Edwards, D. (1990). Constraints on Silurian and Early Devonian phyto-geographic analysis based on megafossils. *Geological Society London Memoirs*, 12, 233–242.
- Ellwood, B. B., Algeo, T. J., Hassani, A. E., Tomkin, J. H., & Rowe, H. D. (2011). Defining the timing and duration of the Kacak interval within the Eifelian/Givetian boundary GSSP, Mech Irdane, Morocco, using geochemical and magnetic susceptibility patterns. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 304, 74–84.
- Ernst, A., May, A., & Marks, S. (2012). Bryozoans, corals, and microfossils of lower Eifelian (Middle Devonian) limestones at Kierspe, Germany. *Facies*, 58, 727–758.
- Escalante, T., Morrone, J. J., & Rodrigues-Tapia, G. (2013). Biogeography regions of North American mammals based on endemism. *Biological Journal of the Linnean Society*, 110(3), 485–714.
- Fagerstrom, J. A., & Bradshaw, M. A. (2002). Early Devonian reefs at Reefton, New Zealand: guilds, origin and paleogeographic significance. *Lethaia*, 35, 35–50.
- Fahraeus, L. E. (1976). Possible Early Devonian Conodontoporoid provinces. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 19, 201–217.
- Fergusson, C. L. (2010). Plate-driven extension and convergence along the East Gondwana active margin: Late Silurian–Middle Devonian tectonics of the Lachlan Fold Belt, Southeastern Australia. *Australian Journal of Earth Sciences: an International Geoscience Journal of the Geological Society of Australia*, 57(5), 627–649.
- Grahn, Y., & Paris, F. (2011). Emergence, biodiversification and extinction of the chitinozoan group. *Geological Magazine*, 148(2), 226–236.
- Hallam, A. (1966). Depositional environment of British Liassic ironstones considered in the contexts of their facies relationships. *Nature*, 209, 1306–1307.
- Hallam, A. (1994). *An outline of phanerozoic biogeography*. Oxford: Oxford University Press.
- Halstead, L. B. (1973). The heterostracan fishes. *Biological Reviews*, 48, 279–332.
- Hamada, T. (1971). Early Devonian brachiopods from the Lesser Khingan district of Northern China. *Paleontological Society of Japan Special Papers*, 15, 1–98.
- Hart, G. F. (1976). Floral realms, palaeomagnetism, and the drifting of the USSR during the phanerozoic. *Geoscience and Man*, 15(1), 133–139.
- Herisse, A. le, Gourvenec, R., & Wicander, R. (1997). Biogeography of Late Silurian and Devonian antiarchs and prasinophytes. *Review of Palaeobotany and Palynology*, 98, 105–124.
- Holland, T. (2010). *Morphology and phylogeny of 'Osteolepiform' fishes: new insights from Australian fossils*. Doctorate: Monash University.
- Holmquist, E. K. (2008). "Paleobiogeography of Devonian Bryozoa in Laurussia." PhD diss., Michigan State University. Department of Geological Sciences.
- Hou, H.-F. (1981). Devonian brachiopod biostratigraphy. *Geological Magazine*, 118(4), 385–391.
- Hou, H.-F., & Boucot, A. J. (1990). The Balkhash-Mongolia-Okhotsk Region of the Old World realm (Devonian). In W. McKerrow & C. R. Scotese (Eds.), *Palaeozoic palaeogeography and biogeography* (pp. 297–303). Bath: The Geological Society Publishing House.
- House, M. R. (1978). Devonian ammonoids from the Appalachians and their bearing on international zonation and correlation. *Palaeontological Association Special Papers*, 21.
- House, M. R. (1996). The Middle Devonian Kacak event. *Proceedings of the USSHER Society*, 9, 79–84.
- House, M. R., & Kerr, W. A. (1989). Ammonoid extinction events. *Philosophical Transaction of the Royal Society London B*, 325(1128), 307–326.
- von Ihering, H. (1892). On the ancient relations between New Zealand and South America. *Transactions and Proceedings of the New Zealand Institute*, 24, 431–445.
- Jansson, J. (1650). *Orbis Terrarum Veteribus Cogniti Typus Geographicus. Cinquième Partie du grand Atlas, contenant une parfaite description du monde maritime, ou hydrographie générale de tout la terre, enrichie des particularités de la Navigation tant Ancienne que Moderne, avec un excellent et curieux tableau du monde des Anciens*. Amsterdam: Jansson.
- Joachimski, M. M., & Buggish, W. (1993). Anoxic events in the late Frasnian—causes of the Frasnian-Famennian faunal crisis? *Geology*, 21(8), 675–678.
- Johanson, Z. (1998). The Upper Devonian fish *Bothriolepis* (Placodermi: Antiarchi) from near Canowindra. *Records of the Australian Museum*, 50(3), 315–348.
- Johanson, Z., & Young, G. C. (1999). New *Bothriolepis* (Antiarchi: Placodermi) from the Braidwood region, New South Wales, Australia (Frasnian). *Records of the Western Australian Museum, Supplement*, 57, 55–75.
- Johnson, J. G., & Boucot, A. J. (1973). Devonian brachiopods. In A. Hallam (Ed.), *Atlas of palaeobiogeography* (pp. 86–96). Amsterdam: Elsevier.

- Johnson, J. G., Klapper, G., & Sandberg, C. A. (1985). Devonian eustatic fluctuations in Euramerica. *Geological Society of America Bulletin*, 96, 567–587.
- Jurina, A. L., & Raskatova, M. G. (2011). Response of higher plants to the Devonian Kacak event (Czech Republic). *Moscow University Geology Bulletin*, 66(1), 37–44.
- Kaiho, K., Yatsu, S., Oba, M., Gorjan, P., Casier, J.-G., & Ikeda, M. (2013). Forest fire and soil erosion event during the Late Devonian mass extinction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 392, 272–280.
- Kazmierczak, J., Kremer, B., & Racki, G. (2012). Late Devonian marine anoxia challenged by benthic cyanobacterial mats. *Geobiology*, 10, 371–383.
- Klapper, G. (1975). Preliminary analysis of Frasnian, Late Devonian conodont biogeography. *Historical Biology*, 10(1), 103–117.
- Klapper, G., & Johnson, J. G. (1980). Endemism and dispersal of Devonian conodonts. *Journal of Paleontology*, 54(2), 400–455.
- Kobayashi, T., & Hamada, T. (1975). Devonian trilobite provinces. *Proceedings of the Japan Academy*, 51(6), 447–451.
- Koch, W. F., & Boucot, A. J. (1982). Temperature fluctuations in the Devonian Eastern Americas realm. *Journal of Paleontology*, 56(1), 240–243.
- Kos'ko, M., & Korago, E. (2009). Review of the New Siberian Islands between the Laptev and the East Siberian Seas, North East Russia. *Stephen Mueller Special Publication*, 4, 45–64.
- Lamotte, D. F. D., Tavakoli-Shirazi, S., Averbuh, O., Mouchot, N., Raulin, C., Lepaementier, F., Blanpied, C., & Ringenbach, J.-C. (2013). Evidence for the late Devonian vertical movements and extensional deformation in northern Africa and Arabia: Integration in the geodynamics of the Devonian world. *Tectonics*, 32, 107–122.
- Leanza, A. F. (1968). Acerca del descubrimiento de ammonoideos devónicos en la República Argentina (*Tornoceras baldisi* n. sp.). *Revista de la Asociación Geológica Argentina*, 24, 326–330.
- Lebedev, O. A., & Zakharenko, G. V. (2010). Global vertebrate-based palaeozoogeographical subdivision for the Givetian-Famennian (Middle-Late Devonian): endemism-cosmopolitanism spectrum as an indicator of interprovincial faunal exchanges. *Palaeoworld*, 19, 186–205.
- Leme, J. M., Meira, F. V. E., Stasi, A. M. D., & Soares, S. P. (2013). The occurrence of phacopid trilobites from Pimenteira Formation at Joao Costa, Piauí, Brazil. *Geological US -Serie Científica*, 13, 17–22.
- Li, R.-U. (2010). Middle Devonian brachiopods from Arctic Canada and some preliminary results of North American biogeography based on quantitative assessment. *Journal of Earth Science*, 21, 36–39.
- Li, Z. X., Powell, C. M., & Trench, A. (1993). Palaeozoic global reconstructions. In J. A. Long (Ed.), *Palaeozoic vertebrate biostratigraphy and biogeography* (pp. 25–53). London: Belhaven Press.
- Lieberman, B. S., & Eldredge, N. (1996). Trilobite biogeography in the Middle Devonian. *Paleobiology*, 22(1), 66–79.
- Lieberman, B. S., & Kloc, G. (1997). Evolutionary and biogeographic patterns in the Asteroptyginae (Trilobita, Devonian) Delo, 1935. *Bulletin of the American Museum of Natural History*, 232, 3–127.
- Lindsey-Griffin, N., Griffin, J. R., & Farmer, J. D. (2008). Palaeogeographic significance of Ediacaran cyclomedusoid within the Antelope Mountain quartzite, Yreka subterranean, eastern Klamath Mountains, California. In R. B. Blodgett & G. D. Stanley (Eds.), *The terrane puzzle: new perspectives on palaeontology and stratigraphy from the North American Cordillera*. Colorado, Geological Society of America.
- Long, J. A. (1986). New ischnacanthid acanthodians from the Early Devonian of Australia, with comments on acanthodian interrelationships. *Zoological Journal of the Linnean Society*, 87, 321–339.
- Long, J., Turner, S., & Young, G. C. (1988). A Devonian fish fauna from subsurface sediments in the eastern Officer Basin, South Australia. *Alcheringa: An Australasian Journal of Palaeontology*, 12(1), 61–78.
- Lopez, H. L., Menni, R. C., Donato, M., & Miquelerena, A. M. (2008). Biogeographical revision of Argentina (Andean and Neotropical Region): an analysis using freshwater fishes. *Journal of Biogeography*, 35(9), 1564–1579.
- Lumbantobing, D. N. (2010). Four new species of the *Rasbora trifasciata*-Group (*Teleostei*: Cyprinidae) from Northwestern Sumatra, Indonesia. *Copeia*, (4), 644–670.
- Ma, X., & Day, J. (2000). Revision of *Tenticospirifer* Tien, 1938, and similar spiriferid brachiopod genera from the Late Devonian (Frasnian) of Eurasia, North America, and Australia. *Journal of Paleontology*, 74(3), 444–463.
- Mark-Kurik, E., & Poldvere, A. (2012). Devonian stratigraphy in Estonia: current state and problems. *Estonian Journal of Earth Sciences*, 61(1), 33–47.
- Marshall, J. E. A., Brown, J. F., & Astin, T. R. (2011). Recognising the Tughanic crisis in the Devonian terrestrial environment and its implications for understanding land-sea interactions. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 304, 165–183.
- McGhee, G. R. (1991). Extinction and diversification in the Devonian Brachiopoda of New York State: no correlation with sea level? *Historical Biology*, 5(2–4), 215–227.
- McKellar, R. G. (2006). Select Lower and Middle Devonian Phacopidae (Trilobita) of southern Morocco. Master of Science, University of Alberta.
- McNamara, K. J., & Feist, R. (2008). Patterns of trilobite evolution and extinction during the Frasnian/Famennian mass extinction, Canning Basin, Western Australia. In I. Rabano, R. Gozalo, & D. Garcia-Bellido (Eds.), *Advances in trilobite research* (pp. 269–274). Madrid: Cuadernos del Museo Geominero.
- McNamara, K. J., Feist, M., & Ebach, M. C. (2009). Patterns of evolution and extinction in the last harpetid trilobites during the Late Devonian (Frasnian). *Palaeontology*, 52(1), 11–33.
- Melo, J. H. G. de (1988). The Malvinokaffric realm in the Devonian of Brazil. *Devonian of the World: Proceedings of the 2nd International Symposium on the Devonian System—Memoir*, 14(1), 669–709.
- Metcalfe, I. (1996). Gondwanaland dispersion, Asian accretion and evolution of eastern Tethys. *Australian Journal of Earth Sciences: an International Geoscience Journal of the Geological Society of Australia*, 43(6), 605–623.
- Meyerhoff, A. A., Boucot, A. J., Meyerhoff, H. D., & Dickins, J. M. (1996). Phanerozoic faunal and floral realms of the earth: the intercalary relations of the Malvinokaffric and Gondwana faunal realms with the Tethyan faunal realm. *Geological Society of America, Memoirs*, 189, 1–78.
- Morrone, J. J. (2014). Biogeographical bioregionalisation of the Neotropical Region. *Zootaxa*, 3782, 1–110.
- Morrone, J. J. (2015a). Biogeographical bioregionalisation of the Andean region. *Zootaxa*, 3936, 207–236.
- Morrone, J. J. (2015b). *Biogeographical bioregionalisation of the world: a reappraisal*. Sydney: Clayton.
- Morrow, D. W. & Geldsetzer, H. H. J. (1988). Devonian of the eastern Canadian Cordillera. Devonian of the World: Proceedings of the 2nd International Symposium on the Devonian System, Memoir, 14(1), 115–140.
- Murphy, A. E., Sageman, B. B., & Hollander, D. J. (2000). Eutrophication by decoupling of the marine biogeochemical cycles of C, N, and P: A mechanism for the late Devonian mass extinction. *Geology*, 28(5), 427–430.
- Neef, G., & Larsen, D. F. (2003). Devonian fluvial strata in and adjacent to the Emsian-Eifelian Moona Vale Trough, western New South Wales. *Australian Journal of Earth Sciences*, 50, 81–91.
- Neubauer, T. A., Harzhauser, M., Kroh, A., Georgopoulou, E., & Mandic, O. (2015). A gastropod-based biogeographic scheme for the European Neogene freshwater systems. *Earth-Science Reviews*, 143, 98–116.



- Oliver, W. A. (1976). Biogeography of rugose corals. *Journal of Paleontology*, 50(3), 365–373.
- Oliver, W. A. (1977). Biogeography of Late Silurian and Devonian rugose corals. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 22, 85–135.
- Oliver, W. A. (1990). Extinctions and migrations of Devonian rugose corals in the Eastern Americas realm. *Lethaia*, 23, 167–178.
- Oliver, W. A., & Pedder, A. E. H. (1989). Origins, migrations, and extinctions of Devonian Rugosa on the North American Plate. *Association of Australasian Palaeontologists*, 8, 231–237.
- Ormiston, A. R. (1968). Lower Devonian trilobites of Hercynian type from the Turkey Creek Inlier, Marshall County, south-central Oklahoma. *Journal of Paleontology*, 42, 1186–1199.
- Pan, J., & Dineley, D. L. (1988). A review of early (Silurian and Devonian) vertebrate biogeography and biostratigraphy of China. *Proceedings of the Royal Society of London, Series B, Biological Sciences*, 235(1278), 29–61.
- Parenti, L. R., & Ebach, M. C. (2009). *Comparative biogeography: discovering and classifying biogeographical patterns of a dynamic earth*. Oakland: University of California Press.
- Pasquo, M. de, Amenabar, C. R., & Noetinger, S. (2009). Middle Devonian microfloras and megaflores from western Argentina and southern Bolivia: their importance in the palaeobiogeographical and palaeoclimatic evolution of western Gondwana. *Geological Society London*, 314, 193–213.
- Pedder, A. E. H., & Murphy, M. A. (2004). Emsian (Lower Devonian) rugosa of Nevada: revision of systematics and stratigraphic ranges, and reassessment of faunal provincialism. *Journal of Paleontology*, 75(5), 838–865.
- Pedder, A. E. H., Jackson, J. H., & Philip, G. M. (1970). Lower Devonian biostratigraphy in the Wee Jasper region of New South Wales. *Journal of Paleontology*, 44(2), 206–251.
- Plusquellec, Y. (2015). First record of the tabulate coral “*Ligulodictyum*” in the Early Emsian of Victoria (Australia), with additional data on Australian *Ligulodictyum* sensu lato. *Royal Society of Victoria*, 127, 17–27.
- Ponciano, L. C. M. O. P., & Della Favera, J. G. (2009). Flood-dominated fluvio-deltaic system: a new depositional model for the Devonian Cabecas Formation, Parnaíba Basin, Piauí, Brazil. *Anais da Academia Brasileira de Ciências*, 81(4), 769–780.
- Postigo Mijarra, J. M., Baron, E., & Gomez Manzaneque, F. (2009). Floristic changes in the Iberian Peninsula and Balearic Islands (South-west Europe) during the Cenozoic. *Journal of Biogeography*, 36(11), 2025–2043.
- Racki, G., Racka, M., Matyja, H., & Devleeschouwer, X. (2002). The Frasnian/Famennian boundary interval in the South Polish-Moravian shelf basins: integrated event-stratigraphical approach. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 181, 251–297.
- Raymond, A. (1987). Paleogeographic distribution of Early Devonian plant traits. *PALAIOS*, 2, 113–132.
- Richter, R. (1941). Devon: Geologische Jahresberichte. *Berlin*, 3A, 31–43.
- Roberts, J., Jones, P. G., Jell, J. S., Jenkins, T. B. H., Marsden, M. A. H., McKellar, R. G., Mckelvey, B. C., & Seddon, G. (1972). Correlation of the Upper Devonian rocks of Australia. *Journal of the Geological Society of Australia*, 18(4), 467–490.
- Rode, A. L., & Lieberman, B. S. (2005). Integrating evolution and biogeography: a case study involving Devonian crustaceans. *Journal of Paleontology*, 79(2), 267–276.
- Rowley, D. B., Raymond, A., Totman Parrish, J., Lottes, A. L., Scotese, C. R., & Ziegler, A. M. (1985). Carboniferous palaeogeographic, phytogeographic, and palaeoclimatic reconstructions. *International Journal of Coal Geology*, 5, 7–42.
- Royer, D. L. (2006). CO<sub>2</sub>-forced climate thresholds during the Phanerozoic. *Geochimica et Cosmochimica Acta*, 70(23), 5665–5675.
- Sandberg, C. A., Ziegler, W., Dreesen, R. & Butler, A. L. (1988). Late Frasnian mass extinction: conodont event stratigraphy, global changes, and possible causes. In *Global catastrophes in earth history: an interdisciplinary conference on impacts, volcanism, and mass mortality*, 673, 160.
- Sanson, N. (1657). *Orbis Vetus, et Orbis Veteris Utraque Continens, Terrarumque Tractus Arcticus, et Antarcticus ex Platone, Theopompo, Sive Aeliano*. Paris: Manilio & Co..
- Schuchert, C. (1903). On the faunal provinces of the middle Devonian of America and the Devonian coral subprovinces of Russia, with two paleogeographic maps. *American Geology*, 32, 137–162.
- Schuchert, C. (1909). Palaeogeography of North America. *Geological Society of America Bulletin*, 20(1), 427–606.
- Sclater, P. L. (1858). On the general geographical distribution of the members of the class Aves. *Zoological Journal of the Linnean Society*, 2, 130–145.
- Scott, J. M. (2013). A review of the location and significance of the boundary between the Western Province and Eastern Province, New Zealand. *New Zealand Journal of Geology and Geophysics*, 2013, 56(4).
- Servais, T., Owen, D. E., Harper, D. A. T., Kroger, B., & Munnecke, A. (2010). The great Ordovician biodiversification event (GOBE): the palaeoecological dimension. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 294, 99–119.
- Servais, T., Cecca, F., Harper, D. A. T., Isozaki, Y., & Niocail, C. M. (2013). Palaeozoic palaeogeographical and palaeobiogeographical nomenclature. In D. A. T. Harper and T. Servais, *Early palaeozoic biogeography and palaeogeography* (38, pp. 25–34). London: The Geological Society.
- Shirley, J. (1938). The fauna of the Baton River beds (Devonian), New Zealand. *Quarterly Journal of the Geological Society (London)*, XCIV(4), 459–506.
- Sole, R. V. and Newman, M. (2002). Extinctions and biodiversity in the fossil record. In *Encyclopaedia of global environmental change: the earth system—biological and ecological dimensions of global environmental change* (2, pp. 297–391). New York: Wiley.
- Stemans, P., Wellman, C. H., & Fitatoff, J. (2007). Palaeophytogeographical and palaeoecological implications of a miopore assemblage of earliest Devonian (Lochkovian) age from Saudi Arabia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 250, 237–254.
- Streel, M., Faison-Demaret, M., & Loboziak, S. (1990). Givetian-Frasnian phytogeography of Euramerica and western Gondwana based on miopore distribution. In W. McKerrow & C. R. Scotese (Eds.), *Palaeozoic palaeogeography and biogeography* (pp. 291–296). Bath: Geological Society.
- Suchý, V., Sýkorová, I., Dobeš, P., Machovič, V., Filip, J., Zeman, A., & Stejskal, M. (2012). Blackened bioclusters and bituminous impregnations in the Koněprusy limestone (lower Devonian), the Barrandian area, Czech Republic: Implications for basin analysis. *Facies*, 58(4), 759–777.
- Suess, E. (1885). *Das Antlitz der Erde*. Leipzig: G. Freytag.
- Talent, J. A., & Yolkin, E. A. (1987). Transgression-regression patterns for the Devonian of Australia and southern West Siberia. *Courier Forschungsinstitut Senckenberg*, 92, 235–249.
- Talent, J. A., Mawson, R., Aitchison, J. C., Becker, R. T., Bell, K. N., Bradshaw, M. A., Burrow, C. J., Cook, A. G., Dargan, G. M., Douglas, J. G., Edgecombe, G. D., Feist, M., Jones, P. J., Long, J., Phillips-Ross, J. R., Pickett, J. W., Playford, G., Rickards, R. B., Webby, B. D., Winchester-Seeto, J. W., Wright, A. J., Young, G. C., & Zhen, Y. Y. (2000). *Devonian palaeobiogeography of Australia and adjoining regions. Palaeobiogeography of Australasian faunas and floras*. In A. J. Wright, G. C. Young, J.



- A. Talent and J. R. Laurie. Canberra: Association of Australasian Palaeontologists.
- Tribouillard, N., Averbuch, O., Devleeschouwer, X., Racki, G., & Riboulleau, A. (2004). Deep-water anoxia over the Frasnian-Famennian boundary (La Serre, France): a tectonically induced oceanic anoxic event? *Terra Nova*, *16*(5), 288–295.
- Van Der Voo, R. (1988). Paleozoic paleogeography of North America, Gondwana, and intervening displaced terranes: Comparisons of paleomagnetism with paleoclimatology and biogeographical patterns. *Geological Society of America Bulletin*, *100*(3), 311–324.
- Van Rooy, J., & Van Wyk, A. E. (2010). The bryofloristic regions of Southern Africa. *Journal of Bryology*, *32*(2), 80–91.
- Vodrazkova, S., Fryda, J., Suttner, T. J., Kopikova, L., & Tonarova, P. (2013). Environmental changes close to the Lower-Middle Devonian boundary; the basal Chotec event in the Prague Basin (Czech Republic). *Facies*, *59*, 425–449.
- Von Raumer, J. F., Stampfli, G. M., Borel, G., & Bussy, F. (2002). Organisation of pre-Variscan basement areas at the north-Gondwanan margin. *International Journal of Earth Sciences*, *91*, 35–52.
- Wallace, A. R. (1876). *The geographical distribution of animals: with a study of the relations of living and extinct faunas as elucidating the past changes of the Earth's surface: in two volumes*. London: Macmillan and Co..
- Wallace, A. R. (1894). What are zoological regions. *Nature*, *49*, 610–613.
- Wang, Y., Boucot, A. J., Rong, J.-Y., & Yang, X.-C. (1984). Silurian and Devonian biogeography of China. *GSA Bulletin*, *95*(3), 265–279.
- Wang, C., Li, N., Sue, Y., & Zong, P. (2011). Distribution of *Tuvaella* brachiopod fauna and its tectonic significance. *Journal of Earth Science*, *22*(1), 11–19.
- Wang, C. W., Zhao, G.-W., Li, N., & Zong, P. (2013). Coevolution of brachiopod palaeobiogeography and tectonopaleogeography during the late Paleozoic in Central Asia. *Science China: Earth Sciences*, *56*(12), 2094–2106.
- Ward, P., Labandeira, C., Laurin, M., & Berner, R. A. (2006). Confirmation of Romer's gap as a low oxygen interval constraining the timing of initial arthropod and vertebrate terrestrialisation. *PNAS*, *103*(45), 16818–16822.
- Waters, J., Carmichael, S. K., Suttner, T. J., Kido, E., Moore, L. M., Batchelor, C. J., & Dereuil, A. A. (2013). Recognition of the Kellwasser and Hangenberg anoxia events in the central Asian Orogenic Belt. 2013 GSA Annual Meeting in Denver.
- Webb, G. E. (1988). Earliest known Carboniferous shallow-water reefs, Gudman Formation (Tn1b), Queensland, Australia: implications for the Late Devonian reef collapse and recovery. *Geology*, *26*(10), 951–954.
- Westermann, G. E. G. (2000). Biochore classification and nomenclature in paleobiogeography: an attempt at order. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *158*, 1–13.
- Wood, G. D. (1995). The Gondwanan acritarch *Bimerga bensonii* gen. et sp. nov.: paleogeographic and biostratigraphic importance in the Devonian Malvinokaffric realm. *Palynology*, *19*(1), 221–231.
- Wright, A. J. (1990). Acastid trilobites from the Baton Formation (Early Devonian), New Zealand. *New Zealand Journal of Geology and Geophysics*, *33*(1), 49–53.
- Yanin, B. T. (2010). On the climatic, climatobiogeographic, and biochorologic units in paleobiogeography. *Paleontological Journal*, *44*(1), 1–10.
- Young, G. C. (1981). Biogeography of Devonian vertebrates. *Alcheringa: an Australasian Journal of Palaeontology*, *5*(3), 225–243.
- Young, G. C. (1986). Cladistic methods in Palaeozoic continental reconstruction. *The Journal of Geology*, *94*(4), 523–537.
- Young, G. C. (1987). Devonian palaeontological data and the Armorica problem. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *60*, 283–304.
- Young, G. C. (2005). An articulated phyllolepid fish (Placodermi) from the Devonian of central Australia: implications for non-marine connections with the Old Red Sandstone continent. *Geological Magazine*, *142*(2), 173–186.
- Young, G. C. (2006). Biostratigraphic and biogeographical context for tetrapod origins during the Devonian: Australian evidence. *Alcheringa: an Australasian Journal of Palaeontology*, *30*(1), 409–428.
- Young, G. C., & Janvier, P. (1999). Early-Middle Palaeozoic vertebrate faunas in relation to Gondwana dispersion and Asian accretion. In I. Metcalfe, R. Jishun, J. Charvet, & S. Hada (Eds.), *Gondwana dispersion and Asian accretion* (pp. 115–140). Rotterdam: A. A. Balkema.
- Young, G. C., Burrow, C., Long, J., Turner, S., & Choo, B. (2010). Devonian macrovertebrate assemblages and biogeography of East Gondwana (Australasia, Antarctica). *Palaeoworld*, *19*, 55–74.
- Zambito, J. I. (2011). The late Middle Devonian (Givetian) global Taghanic biocrisis in its type region (Northern Appalachian Basin): geologically rapid faunal transitions driven by global and local environmental changes. Doctor of Philosophy, University of Cincinnati.
- Zhao, W.-J., & Zhu, M. (2010). Siluro-Devonian vertebrate biostratigraphy and biogeography of China. *Palaeoworld*, *19*, 4–26.
- Zhao, X., Coe, R. S., Gildern, S. A., & Frost, G. M. (1996). Palaeomagnetic constraints on the palaeogeography of China: implications for Gondwanaland. *Australian Journal of Earth Sciences: an International Geoscience Journal of the Geological Society of Australia*, *43*(6), 643–672.
- Zhu, M. (2000). Catalogue of Devonian vertebrates in China, with notes on bio-events. *Courier Forschungsinstitut Senckenberg*, *223*, 373–390.