Atlas of Phanerozoic Oceanic Anoxia

CR Scotese, PALEOMAP Project
TL Moore, PaleoTerra

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This Atlas of Phanerozoic Oceanic Anoxia shows the patterns of oceanic anoxia for 22 time periods from the base of the Cambrian (542 Ma) to the Middle/Late Miocene (Serravallian & Tortonian, 10.5 Ma), plus one additional map for the Neoproterozoic (Middle Ediacaran, 600 Ma). Regions where anoxic conditions may have existed are shown in red. Regions where well-oxygenated waters occurred are shown in blue. Various shades of green, yellow and orange indicate somewhat dysoxic conditions. Red arrows indicate the direction of surface ocean currents during the summer months (June-July-August).

These plate tectonic and paleogeographic maps are the work of C. R. Scotese. The paleoclimate simulations were done by T.L. Moore using the FOAM (Fast Ocean and Atmosphere) Climate Simulation Program. The differences in color and symbology from map to map are due to the fact that these figures were originally published in four separate reports (Scotese et al., 2007; 2008; 2009; & 2011).

These estimates of anoxic oceanic conditions have been made by calculating the degree of “restriction” in each sedimentary basin. Restriction is a quantitative estimate of the degree of connection between any marine region and the open ocean. Restriction values ranged from 0 (not restricted) to 100 (very restricted). For example a marine region that is completely surrounded ocean would be classified as “nonrestricted” and would have a restriction value near zero. On the other hand, a marine embayment that is surrounded mostly by land grid cells would be considered very restricted and would have a high restriction value (>80).

The restriction value was determined by calculating the average distance of each marine grid cell to the nearest land grid cell. Distance measurements were made in 8 compass directions (N,NE,E,SE,S,SW,W,and NW). When the average distance to from each marine grid cell to the nearest land cells was small, it indicated that the marine cell was surrounded by land cells, and hence was “restricted” and likely to be prone to anoxic conditions. Conversely, if the average distance between a marine grid cell and the surrounding land grid cells was very large then it could be inferred that the grid cell was in the “open ocean”, and hence not prone to anoxic conditions. In our approach we use “restriction” as a proxy for oceanic anoxia.

It should be clear from the above description that this simple method of estimating oceanic anoxia does not take into account any geochemical measurements of anoxia, or bring into play any aspects of ocean dynamics (e.g. upwelling, surface currents or salinity). This approach is purely geographical, and consequently, has a few drawbacks. Firstly, high values of anoxia along ocean-facing coastlines are suspect. Also all of the estimates of oceanic anoxia have been made only for surface waters. In other words, the restriction calculation indicates how well connected the surface waters are to the open ocean but doesn’t say anything about the connectedness of the deeper portions of the basin. An exception is the map of oceanic anoxia for the Permo-Triassic Boundary (Map 49, 251 Ma). In this case, the degree of restriction was calculated for a water depth of 1000m. This was done in order to highlight the degree to which the Paleotethys ocean basin was restricted from the Panthalassic ocean basin. The restriction of deep waters in the Paleotethys may have contributed to the global anoxic oceanic conditions that are thought to have played an important role in the great Permo-Triassic extinction.

A third artifact is sometimes apparent in the maps. Because the restriction calculation were made in only the cardinal compass directions, diagonal streaks are sometimes apparent (e.g. Maps 39 and 45).

Despite the simple method employed to estimate oceanic anoxia, some obvious patterns emerge from these maps. Ocean basins are most likely to become restricted, and hence anoxic, at two times during their tectonic history: 1) shortly after their initial opening when they are narrow (Maps 21, 27, 31, and 35), and then again 2) when the ocean basin closes, prior to continent-continent collision (Maps 9, 17, 45, 65 and 75). It therefore comes as no surprise that times of widespread oceanic anoxia, such as the mid-Mesozoic oceanic anoxic events (OAEs), are often coincident with times during which numerous, narrow, poorly connected ocean basins are beginning to open or close.

A complimentary set of surface ocean currents for the winter months (December-January-February) are plotted in the Atlas of Phanerozoic Salinity and Ocean Currents. Though similar to the results shown here, there are maps that show opposite flow directions due to monsoonal changes in wind directions.

The maps are from volumes 1-6 of the PALEOMAP PaleoAtlas for ArcGIS (Scotese, 2014a,b,c,d). Absolute age assignments are from Gradstein, Ogg & Smith (2008).

The following maps are included in the Atlas of Phanerozoic Oceanic Anoxia:

Map 5 Middle/Late Miocene (Serravallian & Tortonian, 10.5 Ma)
Map 7 Early Miocene (Aquitainian & Burdigalian, 19.5 Ma)
Map 9 Early Oligocene (Rupelian, 31.1 Ma)
Map 12 early Middle Eocene (middle Lutetian, 44.6 Ma)
Map 17 Late Cretaceous (Maastrichtian, 68 Ma)
Map 21 Mid-Cretaceous (Turonian, 91.1 Ma)
Map 23 Early Cretaceous (late Albian, 101.8 Ma)
Map 27 Early Cretaceous (early Aptian, 121.8 Ma)
Map 31 Early Cretaceous (Berriasian, 143 Ma)
Map 35 Late Jurassic (Oxfordian, 158.4 Ma)
Map 39 Early Jurassic (Toarcian, 179.3 Ma)
Map 45 Late Triassic (Carnian, 222.6 Ma)
Map 49 Permo-Triassic Boundary (251 Ma)
Map 54 Early Permian (Artinskian, 280 Ma)
Map 57 Late Pennsylvanian (Gzhelian, 301.2 Ma)
Map 63 Middle Mississippian (early Visean, 341.1 Ma)
Map 65 Late Devonian (latest Famennian, 359.2 Ma)
Map 70 Early Devonian (Emsian, 394.3 Ma)
Map 75 Early Silurian (late Llandovery, 432.1 Ma)
Map 82 Early Ordovician (Tremadoc, 480 Ma)
Map 88 Cambrian – Precambrian Boundary (542 Ma)
Map 90 Late Neoproterozoic (Middle Ediacaran, 600 Ma)

This work should be cited as
Scotese, C.R., and Moore, T.L., 2014. Atlas of Phanerozoic Oceanic Anoxia (Mollweide Projection), Volumes 1-6, *PALEOMAP Project* PaleoAtlas for ArcGIS, PALEOMAP Project, Evanston, IL.

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Scotese, C.R., Illich, H., Zumberge, J, and Brown, S., and Moore, T., 2008. The GANDOLPH Project: Year Two Report: Paleogeographic and Paleoclimatic Controls on Hydrocarbon Source Rock Deposition, A Report on the Methods Employed, the Results of the Paleoclimate Simulations (FOAM), and Oils/Source Rock Compilation, Conclusions at the End of Year Two: Miocene (10Ma), Aptian/Albian (120 Ma), Berriasian/Barremian (140 Ma), Late Triassic (220 Ma), and Early Silurian (430 Ma), July, 2008. GeoMark Research Ltd, Houston, Texas, 177 pp.

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Scotese, C.R., 2014f, *The PALEOMAP Project PaleoAtlas for ArcGIS*, version 2, Volume 6, Precambrian Plate Tectonic, Paleogeographic, and Paleoclimatic Reconstructions, Maps 89-103, PALEOMAP Project, Evanston, IL.

Middle/Late Miocene
Serravallian & Tortonian
10.5 Ma

Map 5

Map in Preparation

red areas = anoxic
blue areas = normal
red arrows = summer ocean currents

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Early Miocene

Aquitanian & Burdigalian

19.5 Ma

Map 7

Map in Preparation

red areas = anoxic

blue areas = normal

red arrows = summer ocean currents

Mollweide Projection

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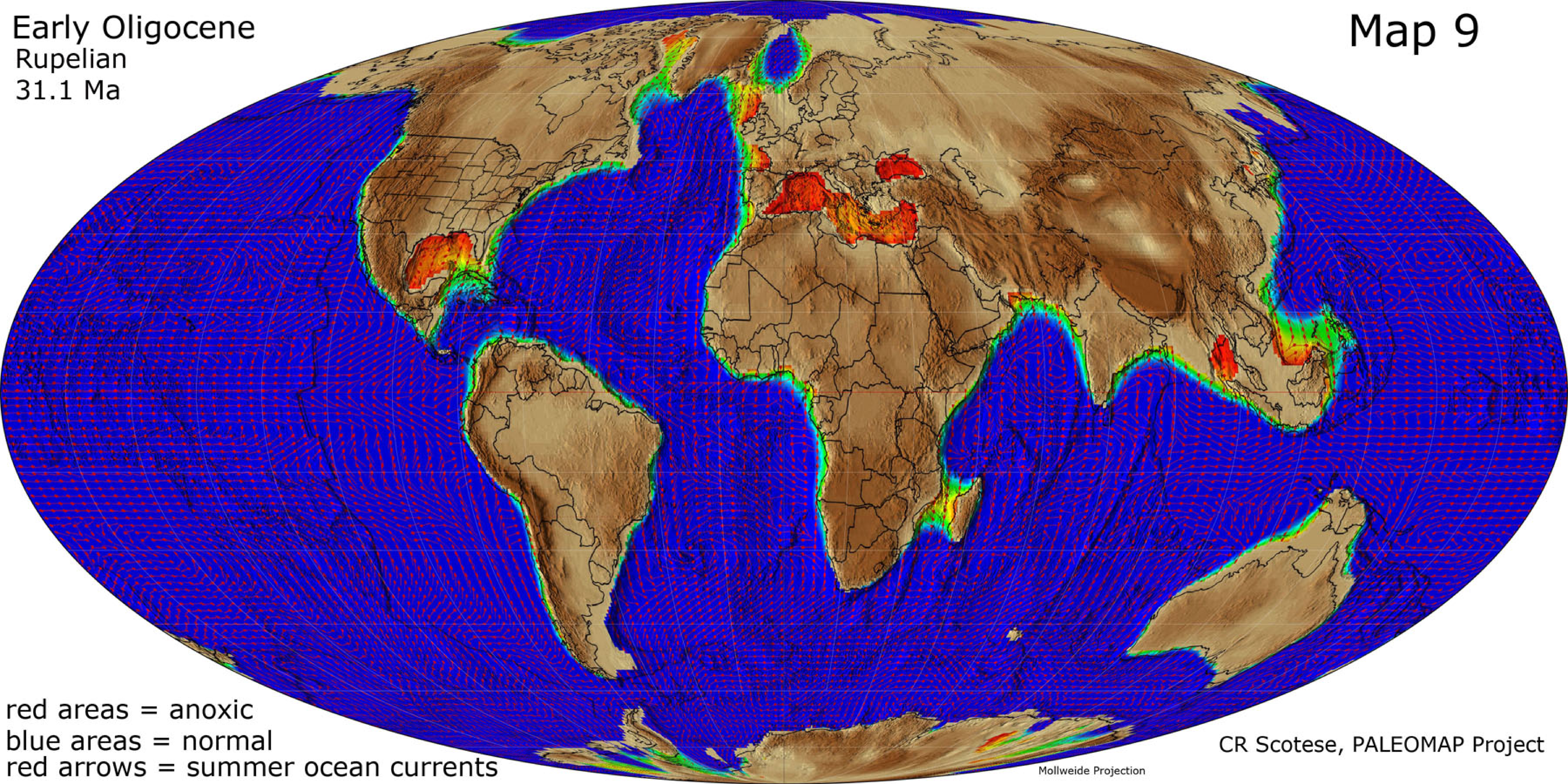
Early Oligocene
Rupelian
31.1 Ma
Map 9
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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Mollweide Projection

early Middle Eocene
middle Lutetian
44.6 Ma

Map 12

Map in Preparation

red areas = anoxic
blue areas = normal
red arrows = summer ocean currents

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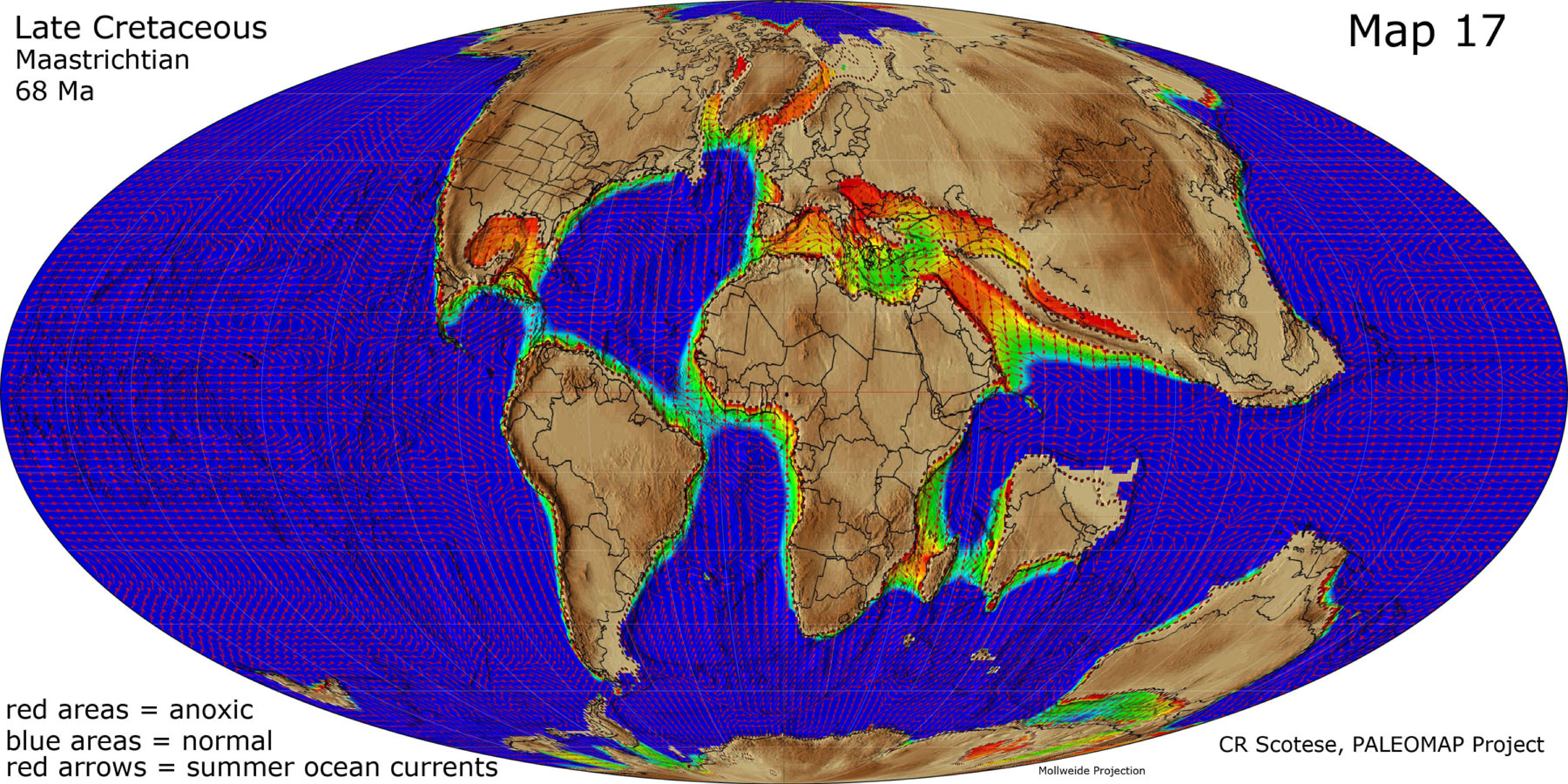
Late Cretaceous
Maastrichtian
68 Ma
Map 17
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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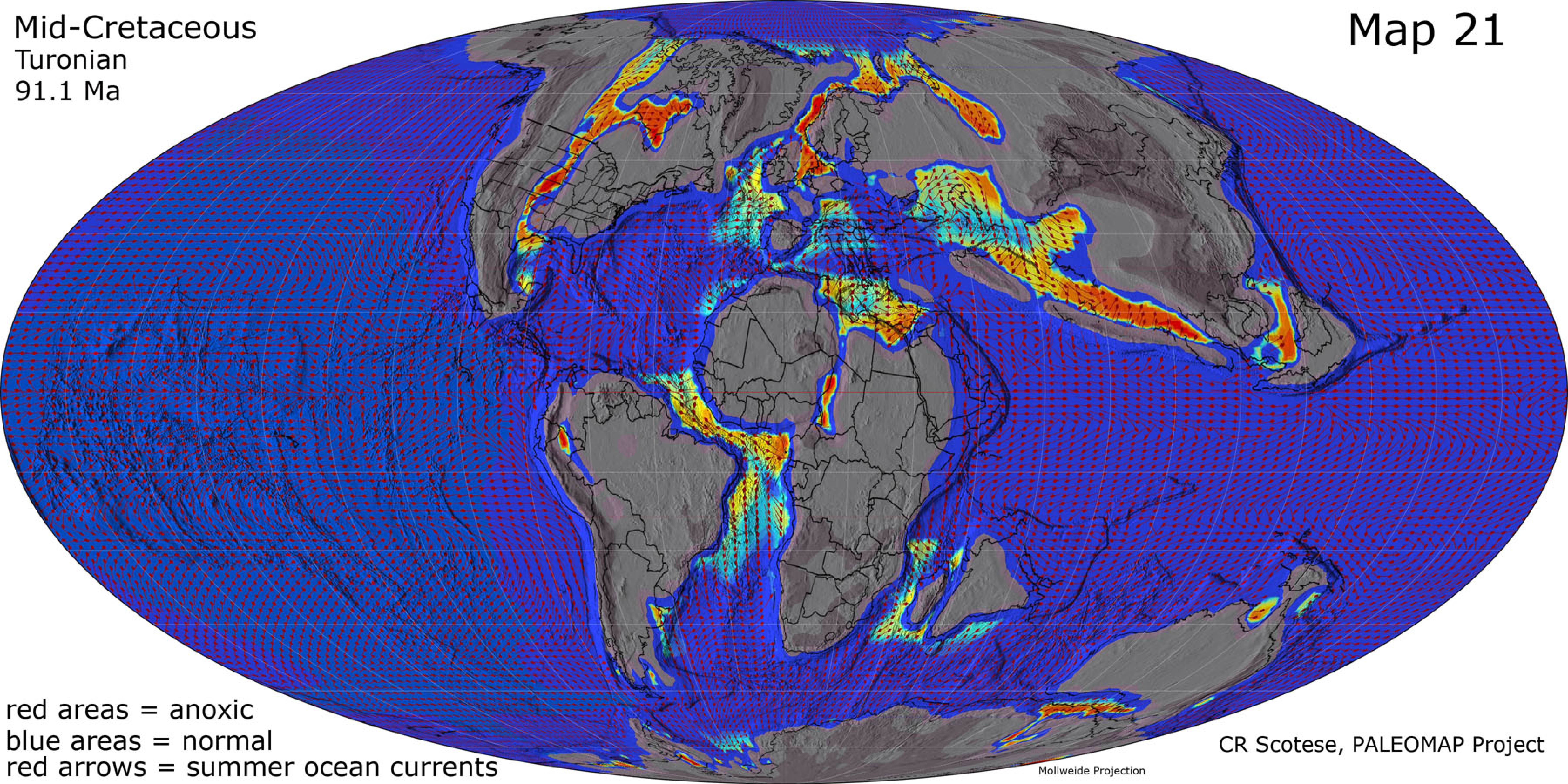
Mollweide Projection


Mid-Cretaceous
Turonian
91.1 Ma
Map 21
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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Early Cretaceous
late Albian
101.8 Ma

Map 23

Map in Preparation

red areas = anoxic
blue areas = normal
red arrows = summer ocean currents

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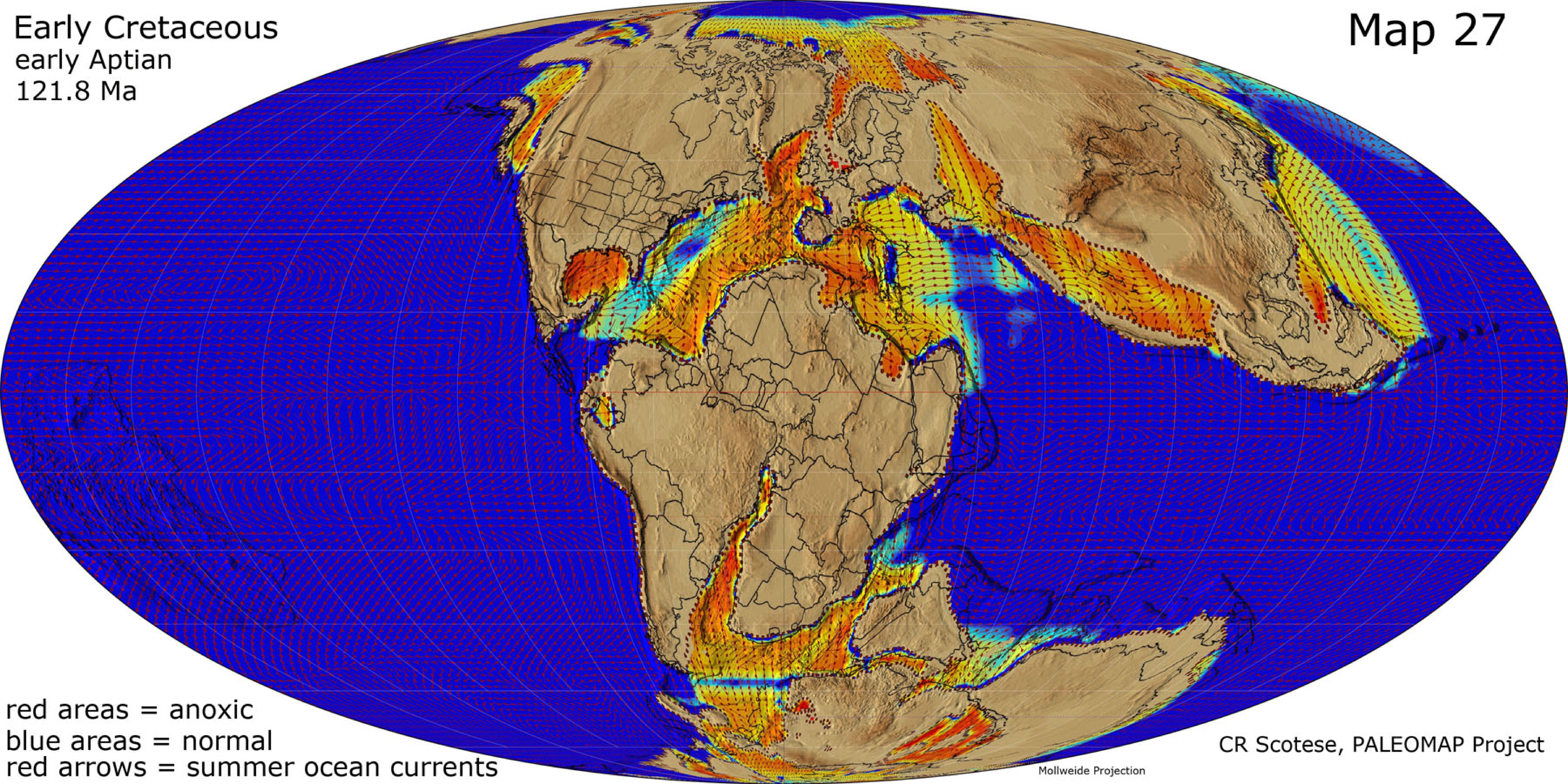
Early Cretaceous
early Aptian
121.8 Ma
Map 27
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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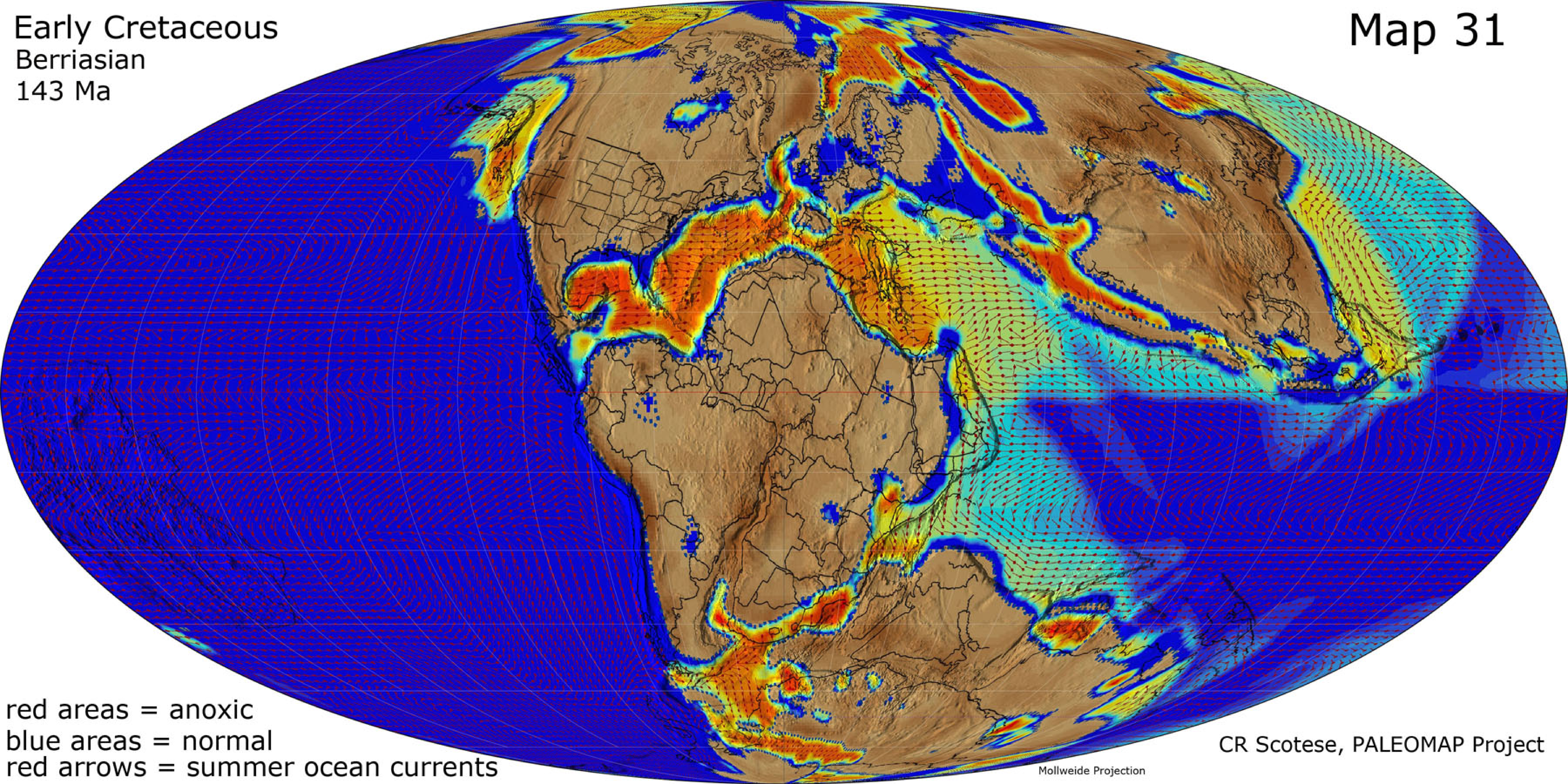
Mollweide Projection


Early Cretaceous
Berriasian
143 Ma
Map 31
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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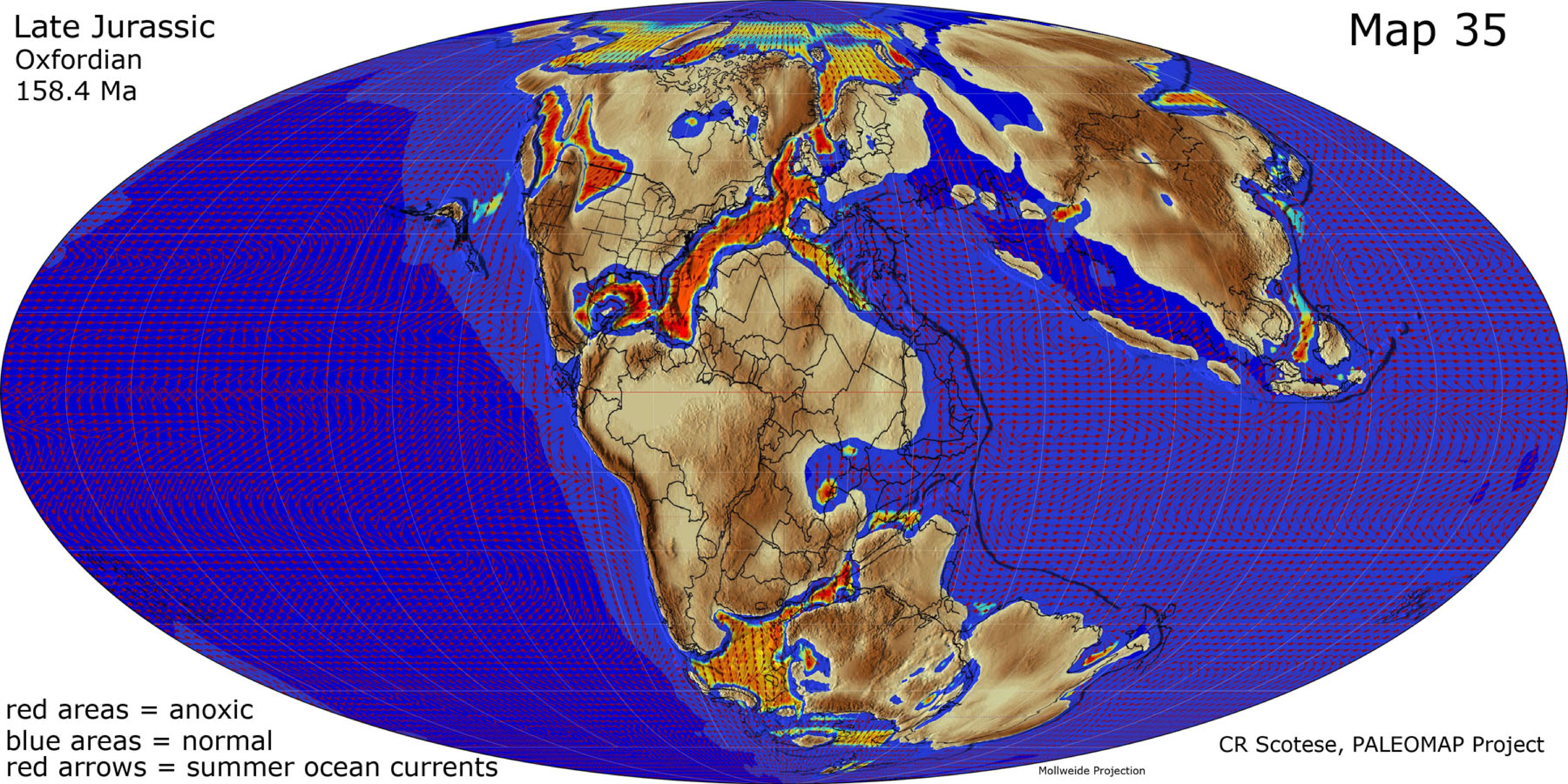
Late Jurassic
Oxfordian
158.4 Ma
Map 35
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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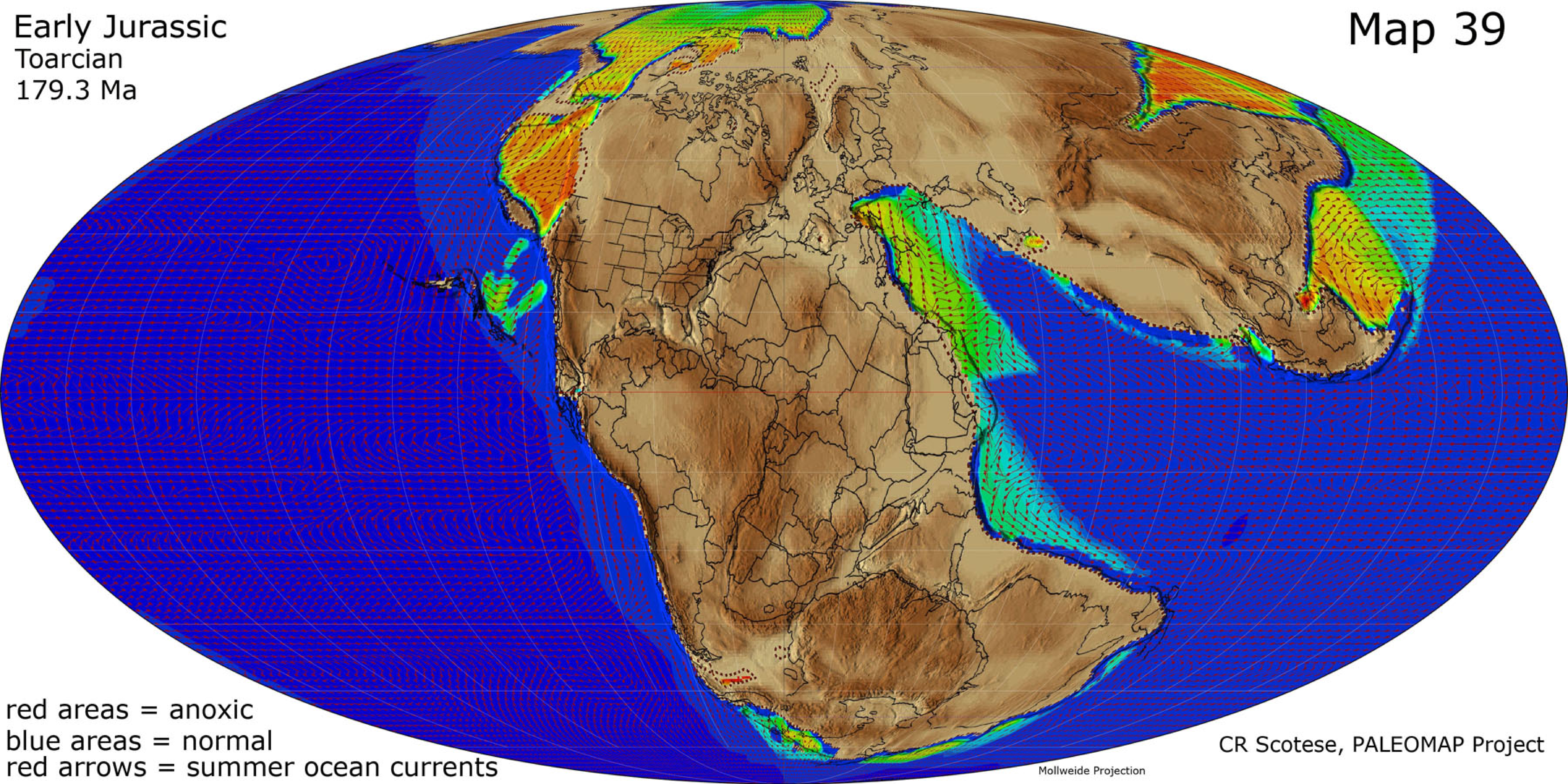

Early Jurassic
Toarcian
179.3 Ma
Map 39
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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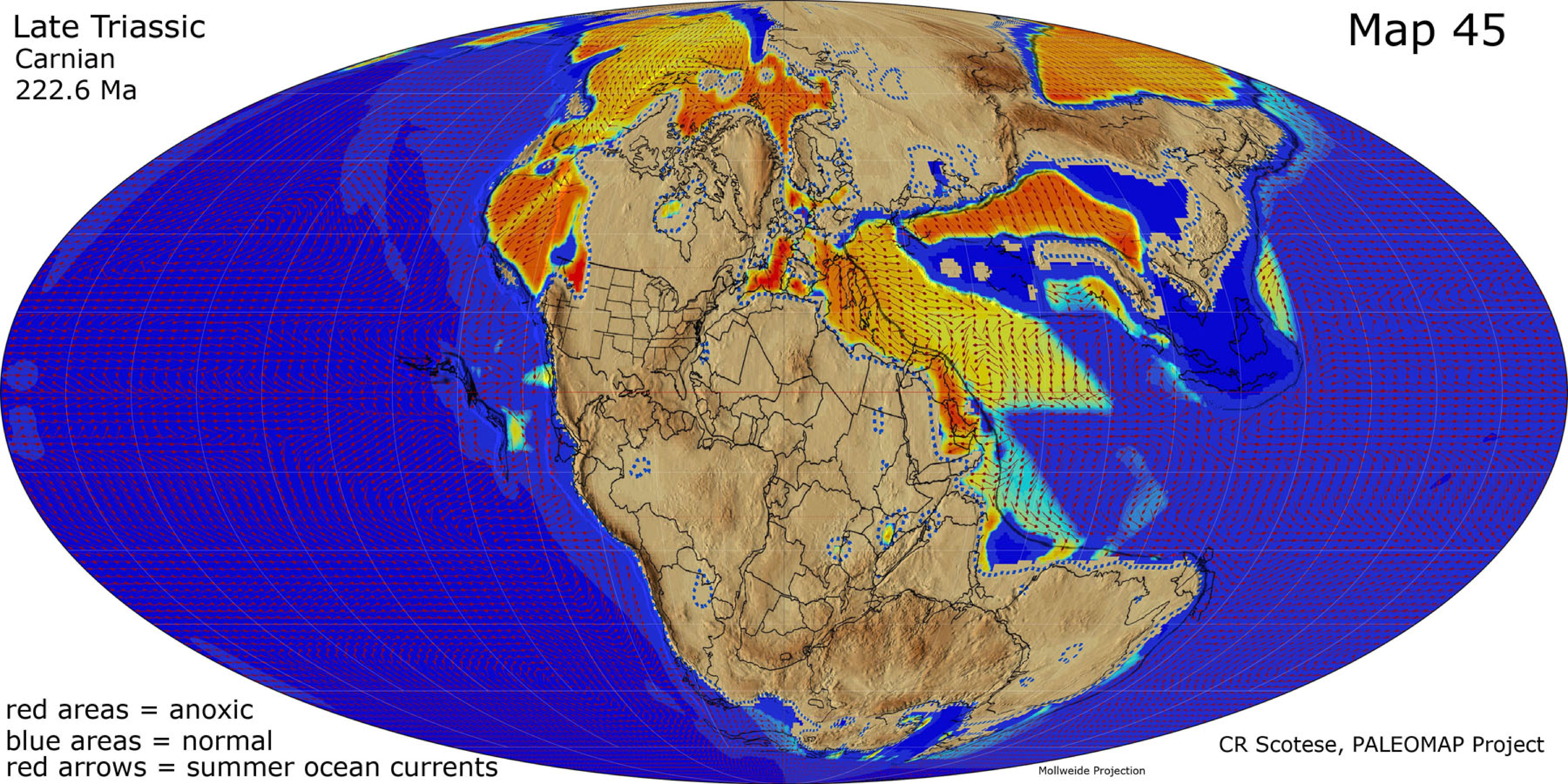
Mollweide Projection


Late Triassic
Carnian
222.6 Ma
Map 45
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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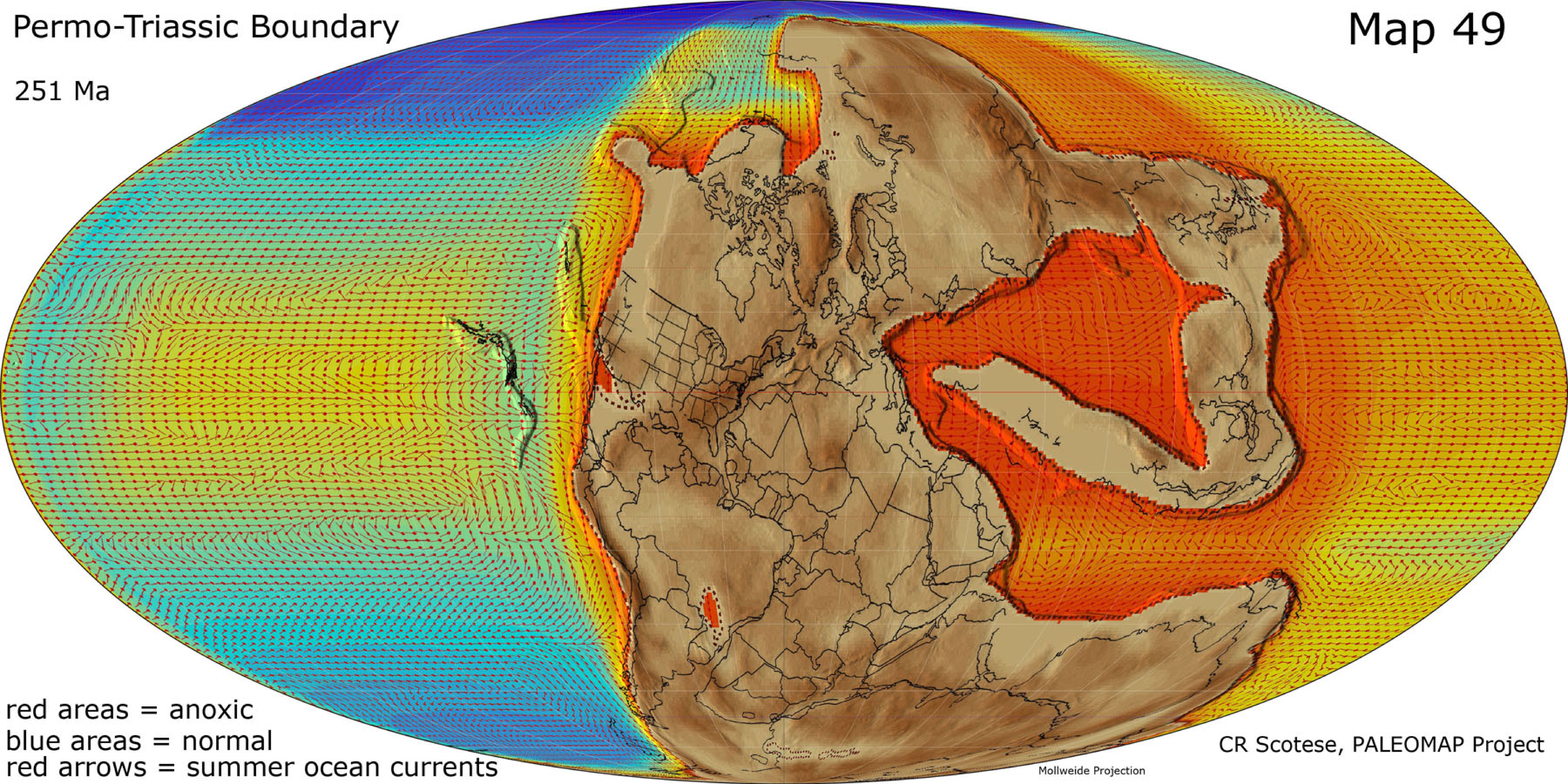
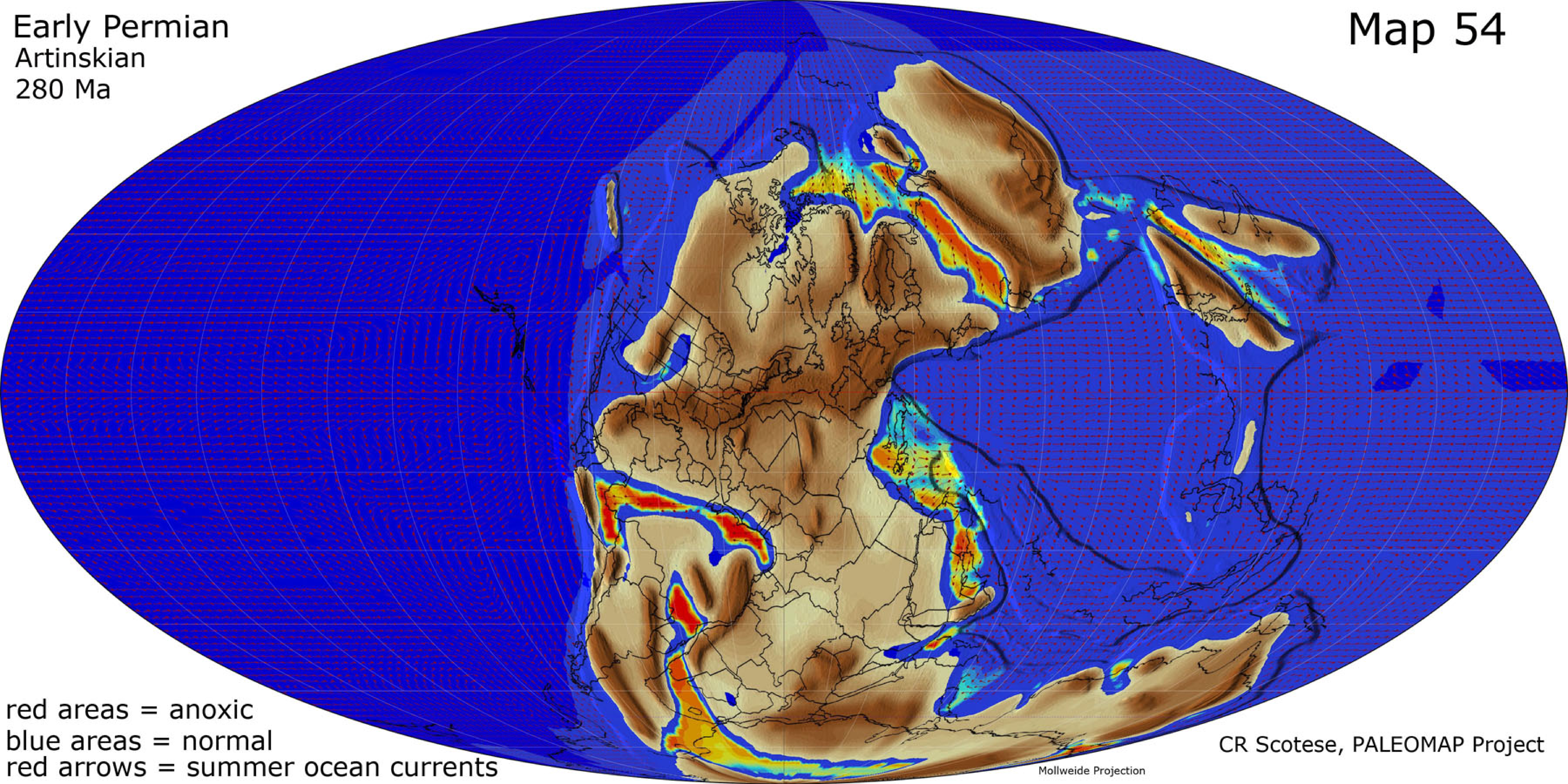

Permo-Triassic Boundary
Map 49
251 Ma
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
CR Scotese, PALEOMAP Project
Mollweide Projection



Early Permian
Artinskian
280 Ma
Map 54
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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Late Pennsylvanian
Gzhelian
301.2 Ma

Map 57

Map in Preparation

red areas = anoxic
blue areas = normal
red arrows = summer ocean currents

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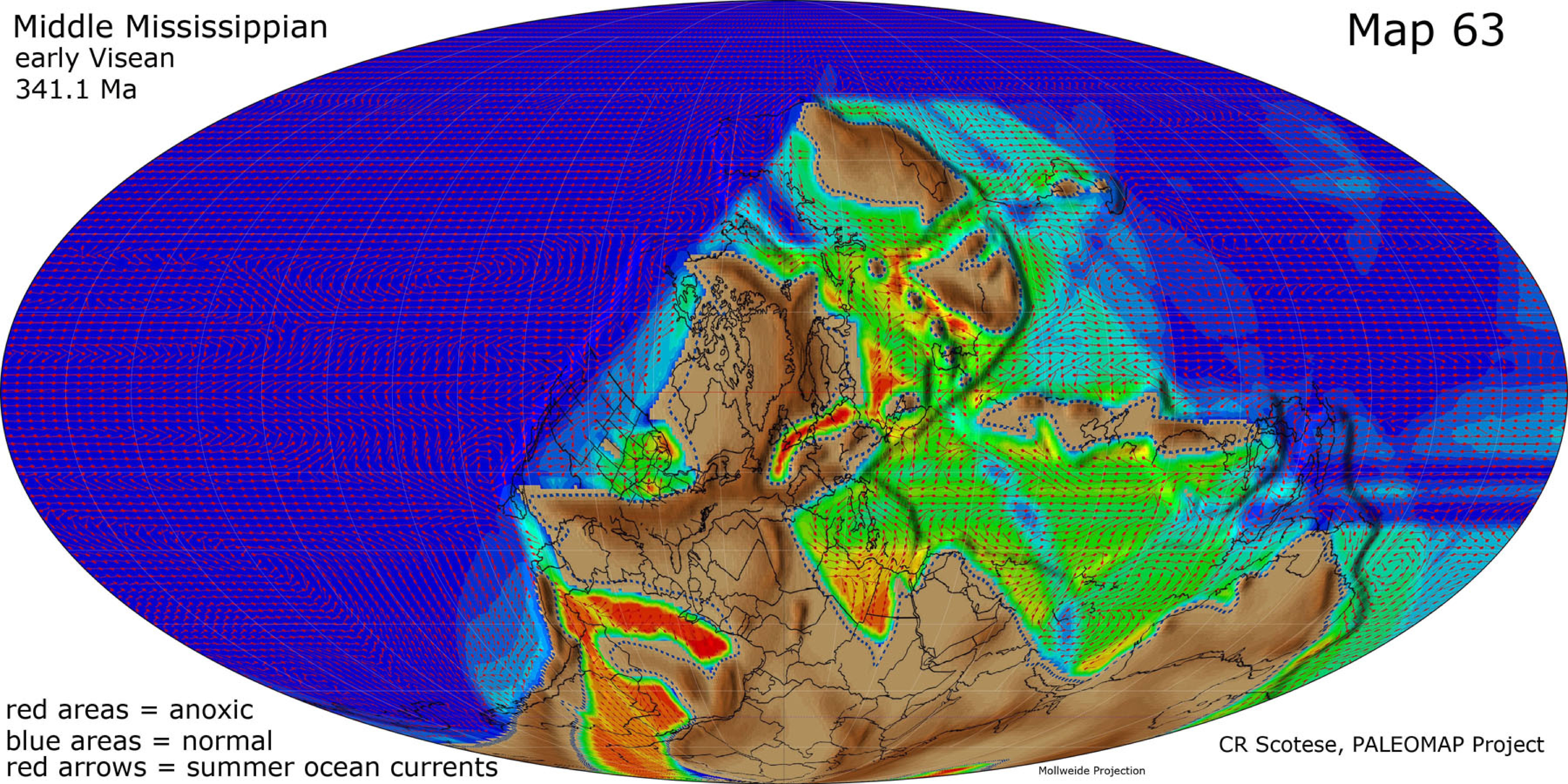
Middle Mississippian
early Visean
341.1 Ma
Map 63
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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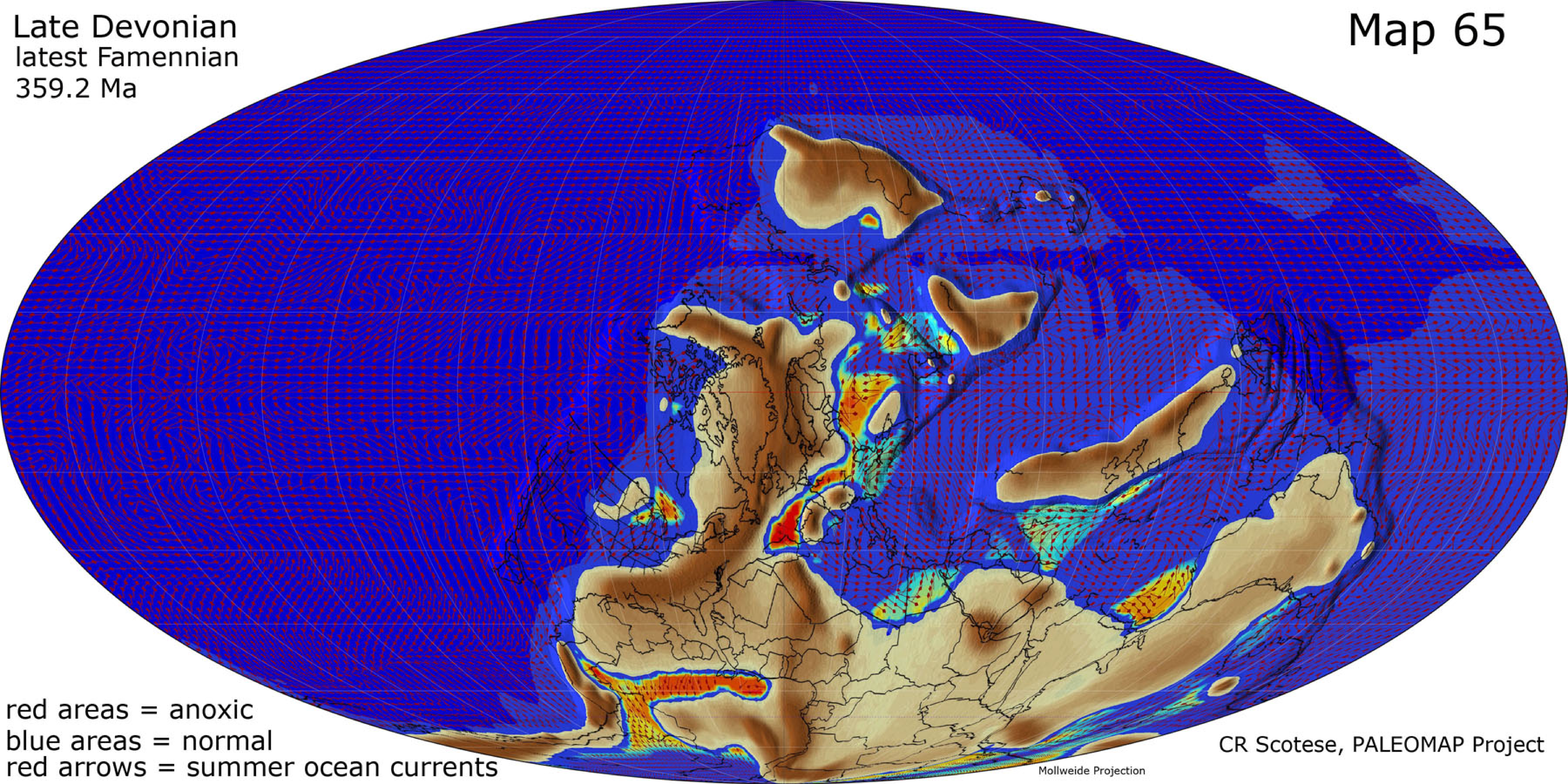
Mollweide Projection



Late Devonian
latest Famennian
359.2 Ma
Map 65
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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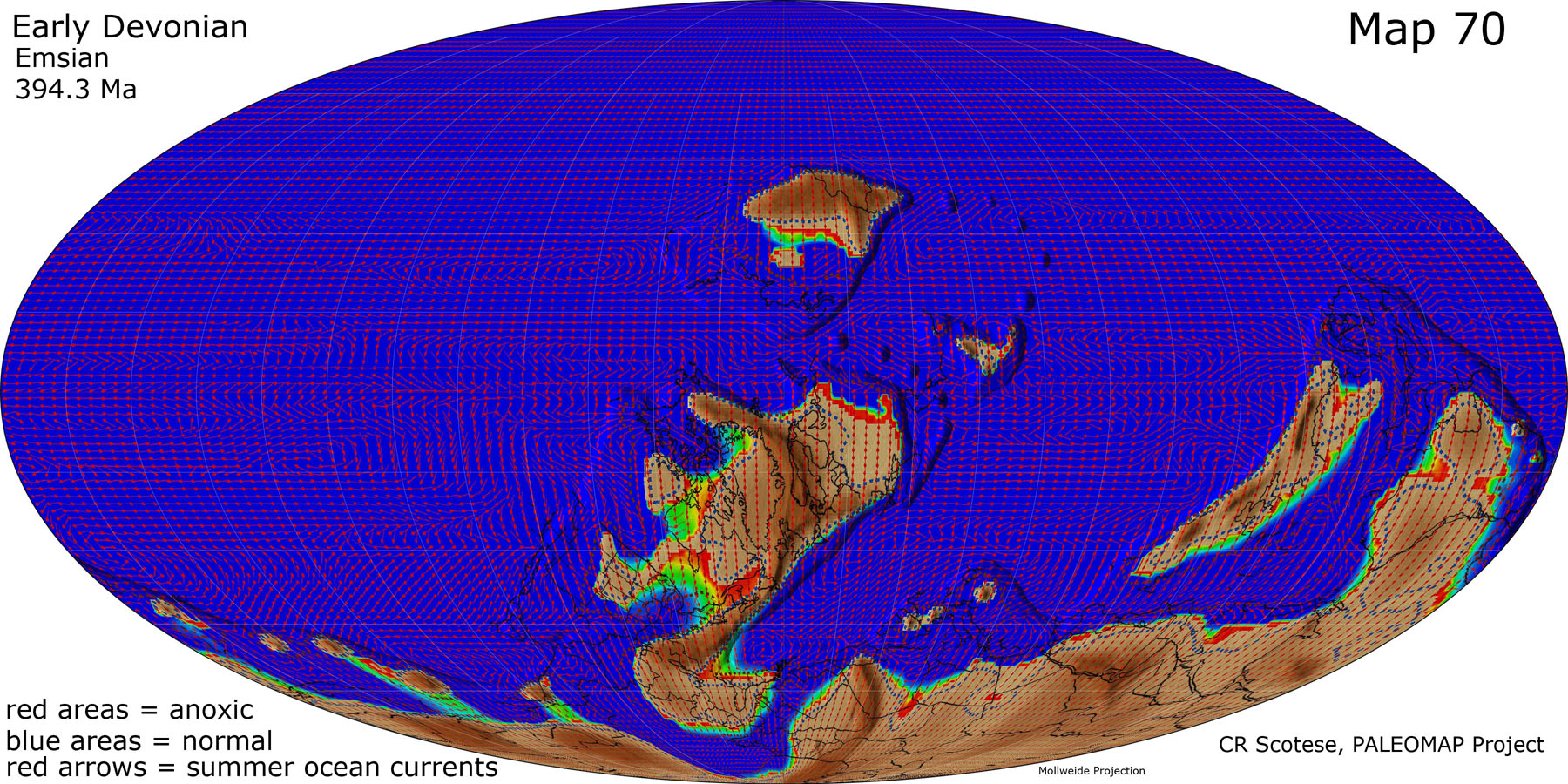
Early Devonian

Emsian

394.3 Ma

Map 70



red areas = anoxic

blue areas = normal

red arrows = summer ocean currents

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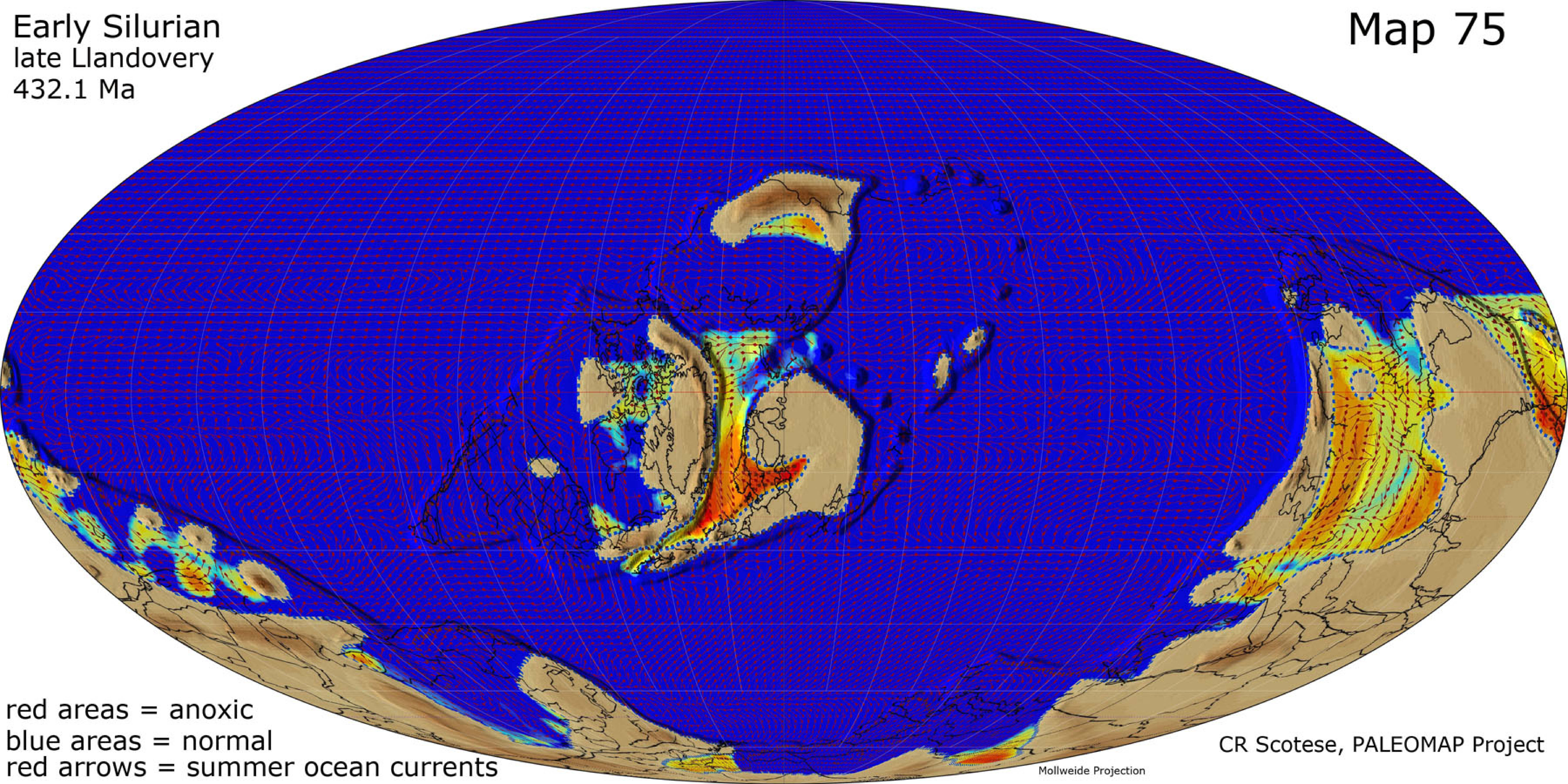
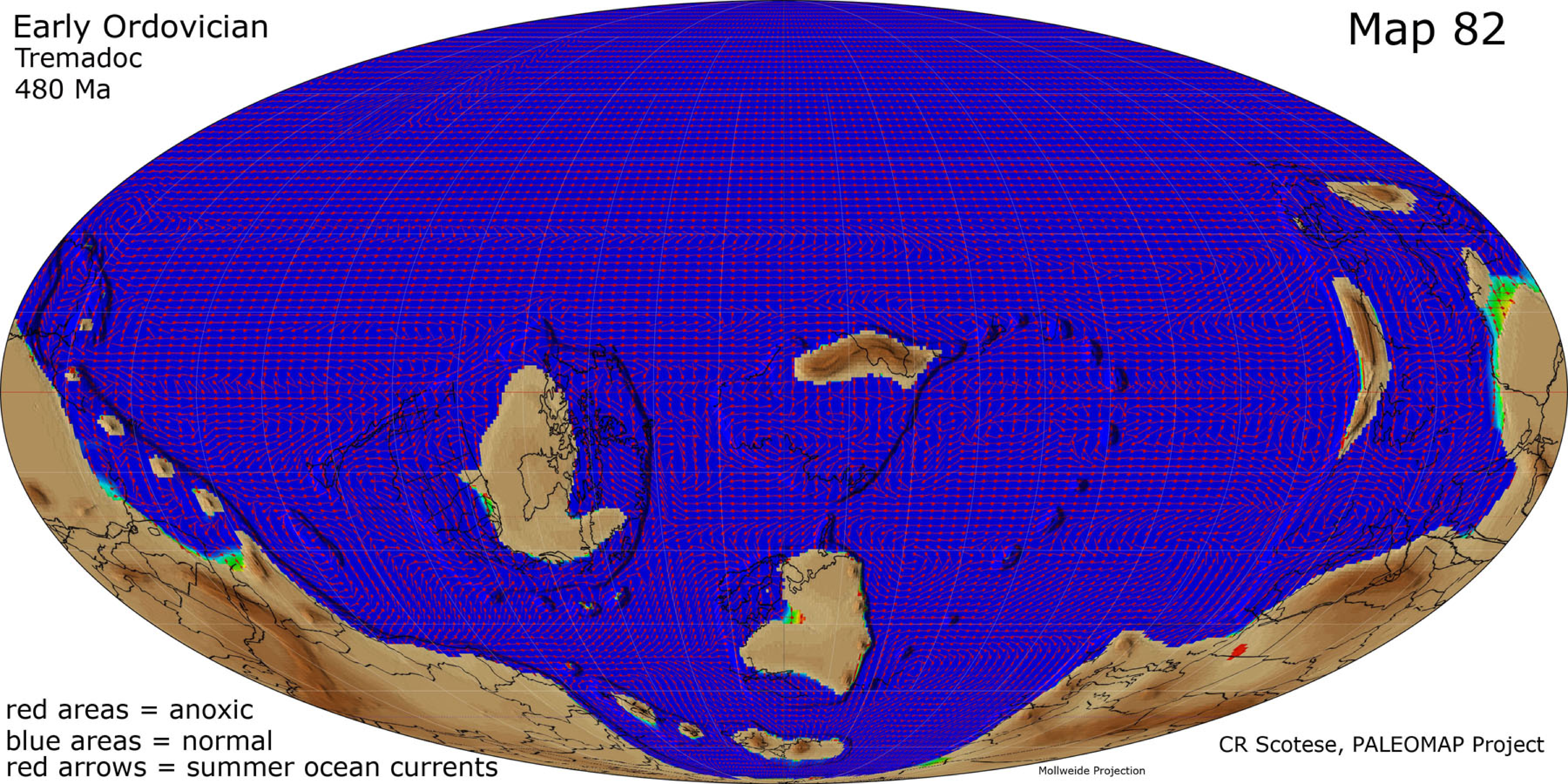


Early Silurian
late Llandovery
432.1 Ma
Map 75
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
CR Scotese, PALEOMAP Project
Mollweide Projection


Early Ordovician
Tremadoc
480 Ma
Map 82
red areas = anoxic
blue areas = normal
red arrows = summer ocean currents
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Cambrian-Precambrian
Boundary
542 Ma

Map 88

Map in Preparation

red areas = anoxic
blue areas = normal
red arrows = summer ocean currents

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Late Neoproterozoic
Middle Ediacaran
600 Ma

Map 90

Map in Preparation

red areas = anoxic
blue areas = normal
red arrows = summer ocean currents

Mollweide Projection

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