COMPARISON OF MARINE AND TERRESTRIAL CLIMATE MODELS TO GEOLOGIC DATA FROM THE PERMIAN-TRIASSIC BOUNDARY

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ABSTRACT

The Permian-Triassic extinction ~252.6 million years ago represents the most severe mass extinction ever recorded. The cause of this extinction is still uncertain, but recent studies in paleoclimate modeling can constrain conditions during this time. The purpose of this study is to determine how well model marine and terrestrial climatic conditions at the Permian-Triassic Boundary correlate to geologic data from that time period. The analysis was done with three assessments: (1) a qualitative correlation of marine and terrestrial climate zones with geologic data, (2) a “hits” versus “misses” correlation analysis, (3) and a statistical correlation using a 1-proportion z-interval test at a 95% confidence level. The results support a strong correlation between the models and geologic data, showing an average 95% confidence level range of (.6788, .8533) throughout the Changhsingian and Induan stages of the Permian-Triassic Boundary. In conclusion, the model results can be used with a high degree of confidence and significantly improve our understanding of paleoclimate.

ACKNOWLEDGEMENTS

This research project could not have been completed without the help from many extraordinary people. First, I would like to thank Angela Osen and Dr. Arne Winguth for guiding me through the programming language, advancing my knowledge of the Permian-Triassic Boundary, and providing me the opportunity to work alongside them, their expertise was critical towards my success. Second, I would like to thank Dr. Julie Bartley who provided me with the opportunity to research this topic and over the years has taught me the skills necessary to understand and connect the many geologic concepts associated with this project. Third, I thank Dr. Jim Welsh for his contributions of geologic information. I would also like to thank Dr. Carolyn Dobler for helping me understand the statistics of a multivariable problem. Lastly, I would like to thank Dr. Laura Triplett who has continuously provided me with the motivation to pursue my passion of geology and has mentored me to become the geologist I am today. This project was partially funded by the Geology Department at Gustavus Adolphus College.

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INTRODUCTION

Recently, climate research has incorporated greater and more advanced modeling studies to interpret past, present, and future climate. One past climate of particular interest for many scientists has been the Permian-Triassic Boundary (PTB) 252.6 million years ago (Ma) (Mundil et al., 2004), where it is thought that 82% of genera and fully half of all marine families disappeared (Erwin et al., 2006). This extinction event is not completely understood, but many speculate the marine and terrestrial ecosystem collapse was associated with changes in the global carbon cycle (Twitchett et al., 2001) along with ocean stratification and anoxia (Isozaki et al., 1997). For this study we focus on understanding marine and terrestrial climate conditions from models and compare them with geologic data to help refine knowledge of the PTB paleoclimate.

Modeling studies are helpful in explaining patterns of change in climate, but must be rigorously tested to make sure they are accurately portraying the "real world". Correlation studies are needed to determine how well the modeling results compare with historical measurements and geologic records of past climates.

Significant advances have been made in understanding paleoceanography during the PTB using multiple modeling programs. For example, Winguth et al. (2002) simulated warm polar ocean currents during the PTB and previously questioned how well oceanic and continental climate conditions agree with geologic evidence based on Ziegler et al. (1998). That study qualitatively assessed how well each of the climate sensitive sediments matched the modeled climate zones from the GENESIS 2 climate model. The best agreement occurred under model conditions with 4x modern CO_2 levels (Winguth et al., 2002). Montenegro et al. (2011) found good general agreement between their fully coupled model (UVic ESCM) and geologic evidence from the PTB interval. Both studies, although encouraging, were only qualitative in nature; further quantitative analysis is needed. Additionally, Winguth et al. (2002) indicated that future studies should use a fully coupled atmosphere-ocean-land model

The fully coupled climate carbon cycle model, Community Climate Systems Model version 3 (CCSM3) is based on the boundary conditions established in an earlier modeling study of the PTB (Kiehl and Shields, 2005). With these boundary conditions, we established parameters for a marine climate model during the Modern and PTB, depicting eight characterized zones based on Ziegler et al. (1998). Using the model results of climate zones from CCSM3, along with terrestrial climate zones (Rees et al., 2002), we explore the relationship with geologic data (Ziegler et al., 1998, 2003) from the PTB. In this study we use three correlation assessments; (1) a qualitative correlation of marine and terrestrial climate zones with geologic data, (2) a "hits" versus "misses" correlation analysis, (3) and a statistical correlation using a 1-proportion z-interval test at a 95% confidence level.

GEOLOGIC SETTING

The boundary between the Permian and Triassic periods was a time during which the continental interiors were extremely arid and there were no glaciers present (Erwin et al., 2006). The arid environment of the late Permian brought about expansions of desert belts, red beds, eolian dunes, and areas of evaporite formation (Parrish, 1993). A majority of the land masses were compiled into the supercontinent Pangea and oceans were vast. The Tethys Seaway occupied the mid-latitudes East of the Pangean land masses, which had narrow and partially isolated marine basins separating them (**Figure 1**). Oceanic conditions during the PTB were potentially euxinic in the shallow marine platforms (Algeo et al., 2010). The exact position of the land masses is still under debate, but the general consensus is that they were conglomerated together, with the Tethys being open to the ocean currents.

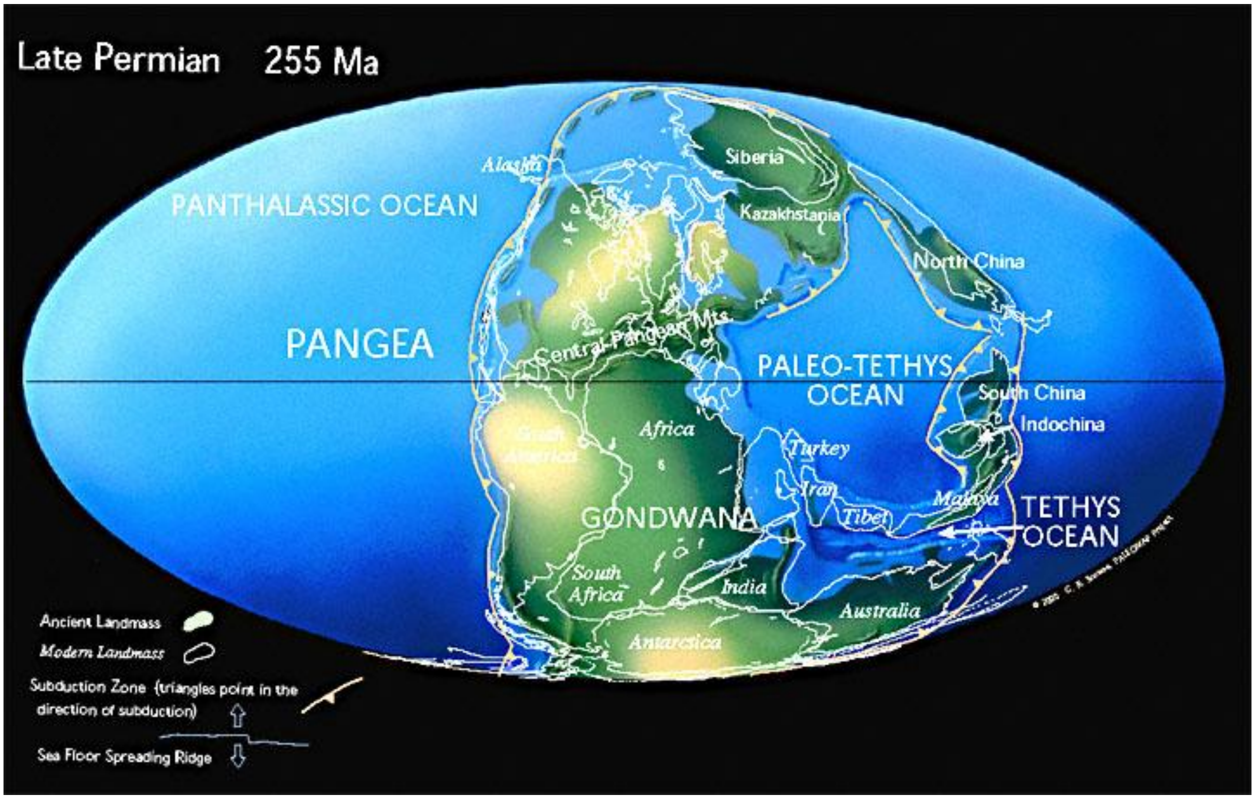

Figure 1: The Paleogeography of the late Permian. Source: Scotese Paleomap Project.

The focus of this thesis is in the late Permian to early Triassic period, specifically the Changhsingian to the Induan stages (253.8-249.5 Ma). Geologic information from Rees et al. (2002) is derived from the Wordian Stage (265.8 Ma). The environment is conjectural based upon Kiehl and Shields. (2005) CCSM3 model parameters, which attempt to follow evidence already discovered about the Permian in hopes to simulate global climate during the time frame.

RESEARCH METHODS

The first step in this study was to digitize the data from Ziegler et al.'s (1998) mini atlas for the PTB periods along with Modern day. This mini atlas displays the spatial distribution of geologic data during the period, which gives an indication of climate conditions. Using Adobe Illustrator, high resolution images were scanned and scaled accurately to overlay with Modern and Permian model outputs of land from the CCSM3 (Kiehl and Shields., 2005). Once aligned, the geologic data were placed precisely where they occur in the mini atlas of Ziegler et al. (1998). Then the base map from Ziegler et al. (1998) was removed leaving only the CCSM3 model output map of land and the geologic data points. A collection of points near the coast of South America on the Tethys seaway side in the Permian map from the Changhsingian needed to be moved only slightly due to differences in map scale from Ziegler and the model output of land. This slight move should not have an effect on the study because climate zones mainly vary with north south movement and the points were only moved slightly west. This method of digitizing points was done for the Induan Stage as well as the Modern using data from Ziegler et al. (1998, 2003).

Parameters were established for the CCSM3 based on marine climate zone parameters of Ziegler et al. (1998) (**Table 1**). Model parameters were constrained to classify marine climate across eight different zones; glacial, cold temperate, wet temperate, temperate, upwelling, dry subtropical, tropical, and wet tropical.

In Model	Description	Temp (°C)	Salt (g/kg)	WVEL (m/s-1)
1	Glacial	<-1.8		
2	Cold Temperate	-1.8-0		
3	Wet Temperate	0-20	<32	
4	Temperate	0-20	32-37	
5	Upwelling			>1x10^-6
6	Dry Subtropical		>37	
7	Tropical	>20	32-37	
8	Wet Tropical	>20	<32	

Table 1: Model parameters for marine climate zones following Ziegler et al. (1998). In order to run efficiently and to minimize space; description, temp, salt, and WVEL are defined by a single digit in the model.

A map for both the PTB marine climate conditions and the Modern were produced after the model was run. This map was similar to the CCSM3 model output of land, but now contained the 8 marine climate regimes. Geologic data points were overlain onto these marine climate zone model images for all the stages. The Modern map comparison was used to evaluate whether the CCSM3 model was working correctly. CCSM3 contains 24 depth levels in the upwelling parameter; this study used a depth level of 102.62 meters to provide an average upwelling rate.

Additional terrestrial climate model studies were sought to correlate geologic points that were located within the PTB landmass. Rees et al. (2002) conducted a study of biome regimes to model terrestrial climate zones during the PTB. We used their results from the Wordian Stage (265.8 Ma), the dataset closest in age to the PTB. The model output of Rees et al. (2002) was scaled and overlaid on the maps in this study using Adobe Illustrator. Correlation of the legends from the two geologic datasets

(Ziegler et al.’s, 1998 and Rees et al.’s, 2002) was established based on information provided by the authors regarding climate zonation and geologic data present for those zones (**Table 2**). Because of major uncertainty in the relationship of oil source points to climate, this parameter was left uncorrelated.

Climate Zone (Ziegler)	**Climate Zone (Rees)**	**Coals**	**Evaporite**	**Reefs/Carb**	**Tills**	**Phosphorite**	**Organic Rich**	**Eolian Sands**	**Organic Buildup**	**Oil Source**
Glacial	Tundra				X					
Cold Temperate	Cold Temperate	X			X					
Wet Temperate	Cool Temp/Winter Wet	X					X			
Temperate	Warm Temperate		X					X		
Upwelling						X	X			
Dry Subtropical	Mid-Latitude Desert/Desert		X					X		
Tropical	Tropical Summer	X		X					X	
Wet Tropical	Tropical Ever wet	X		X			X		X	

Table 2: Correlation of climate zones from Ziegler et al. (1998) and Rees et al. (2002) with geologic data.

Analysis of the degree of correlation between geologic data and model climate zones was conducted using three assessments; **(1)** a qualitative correlation of marine and terrestrial climate zones with geologic data, **(2)** a “hits” versus “misses” correlation analysis, **(3)** and a statistical correlation using a 1-proportion z-interval test at a 95% confidence level.

(1) The qualitative correlation of marine and terrestrial climate zones with geologic data was based on comparison of geologic points to climate zones and how well they appeared to match up with their respective zone of occurrence from **Table 2.**

(2) A "hits" versus "misses" correlation analysis provided basic quantitative assessment of how well the geologic points matched up with modeled climate zones. Each geologic point was evaluated and points that fell within the correct climate model zone, according to the matrix in **Table 2**, was scored as a "hit"; if it lay outside its zone, it was scored as a "miss". The percentage of "hits" was reported.

(3) The statistical analysis of the 1-proportion z-interval test at a 95% confidence level provided a further step in quantitative understanding. This test is used to evaluate whether data correlation can be explained by random overlap, or whether the correlation is non-random. The null hypothesis (random correlation) is considered falsified if non-random behavior is supported at the 95% confidence level. **Equation 1** computes, for each category, a percentage value necessary for the correlation to falsify the null hypothesis.

$$p \pm z_{1-\alpha/2}\sqrt{\frac{p(1-p)}{n}}$$

Equation 1: 1-proportion z-interval test at a 95% confidence level (Mayfield, 2011).

p=Sample proportion=x/n

z= Z value at 95% confidence interval=1.96

n= Sample size

RESULTS

Results are broken down into three assessments, **(1)** a qualitative correlation of marine and terrestrial climate zones with geologic data, **(2)** a “hits” versus “misses” correlation analysis, and **(3)** a statistical correlation using a 1-proportion z-interval test at a 95% confidence level.

(1) Comparisons for the Modern, Induan, and Changhsingian (**Figures 2-4**) show a strong correlation between geologic data and modeled marine climate zones. Qualitative observations of the Modern (**Figure 2**) show a relationship of certain geologic points occurring only within specific marine climate zones. Reefs in particular provide a strong correspondence with the tropical zone, evaporites follow a similar trend in the dry subtropical zone, and tills correlate well to the cold temperate zone. Coals in the Modern period are observed to be forming in a variety of climatic environments.

In the Induan comparison (**Figure 3**), evaporites occur consistently near 30° latitude with minor discrepancies occurring in the southern hemisphere, where a majority of the landmass is located. Reefs and carbonates correlate well to the tropical zone of the marine climate model. There are two outlier points for carbonates that occur in extremely high northern latitudes.

The Changhsingian comparison (**Figure 4**) contains 109 geologic points and has similar correlation patterns with marine climate model zones. A majority of geologic points in this time frame are evaporites, which occur tightly packed together in northern latitudes within the landmass area. Minor discrepancies occur throughout the geologic points, including oil source rocks and coals, which appear randomly distributed around the Earth.

The comparison among Rees et al.’s (2002) terrestrial climate zones, the marine climate zones, and geologic data for the Induan and Changhsingian provides greater correlative assessment. The Induan Model climate zones show a relatively strong correlation with Rees’s climate zones overlay

(**Figure 5**). Similarly, the Changhsingian geologic data correlate well with modeled terrestrial climate zones (**Figure 6**).

(2) A basic comparison in a "hit-miss" analysis produced high percentages of correlation between the geologic data and the modeled marine (CCSM3) and terrestrial (Rees et al., 2002) climate zones (**Tables 3-4**).

The Induan Stage "hit-miss" analysis (**Table 3**) shows strong correlation for the three types of available geologic points; 86.36% of evaporites, 73.33% of carbonates, and 100% of reefs "hit" an appropriate zone. The Changhsingian Stage dataset contains more kinds of geologic points to correlate (**Table 4**); 81.81% of coals, 90.32% of evaporites, 0% of phosphates, 100% of eolian sands, and 81.25% of organic buildups "hit" an appropriate zone. Several "misses" did occur in both the Induan and the Changhsingian. The Induan had 12 misses within the carbonates and the Changhsingian had six misses in evaporites. **Table (2)** shows details of the correlation.

(3) Using a 1-proportion z interval test at a 95 % confidence level, ranges of accuracy were computed. The Induan evaporites ranged from (.720, 1.007), carbonates ranged from (.604, .862), and reefs ranged from (1, 1) (**Table 5**). The Changhsingian provided similar statistics with coals ranging between (.657, .979), evaporites ranging from (.829, .976), phosphorites and eolian sands ranged from (0, 0) and (1, 1) respectively. Finally organic buildups ranged from (.621, 1.003) (**Table 6**).

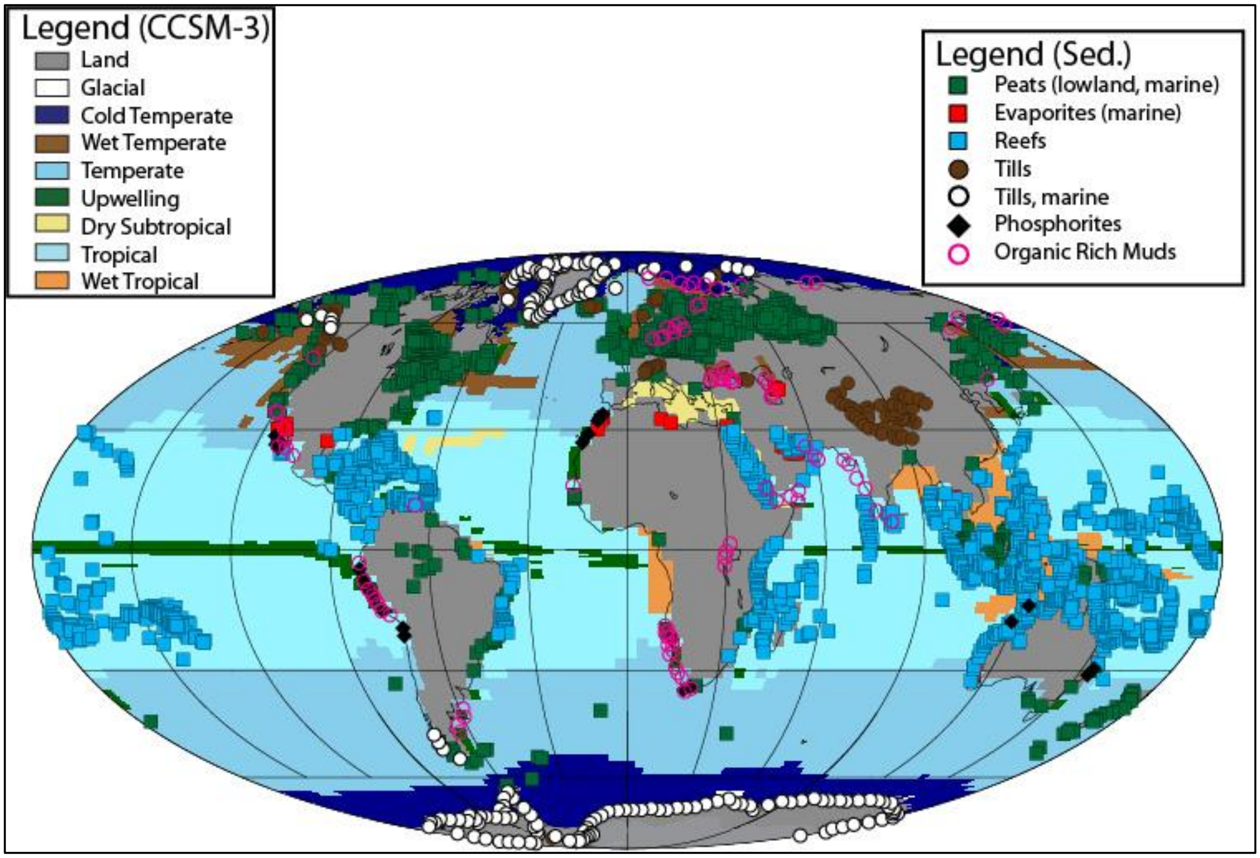

Figure 2: Comparison of marine climate zones from CCSM3 with geologic data from the Modern (Ziegler et al., 1998). Colors from the CCSM3 represent different climate regimes, with land being gray.

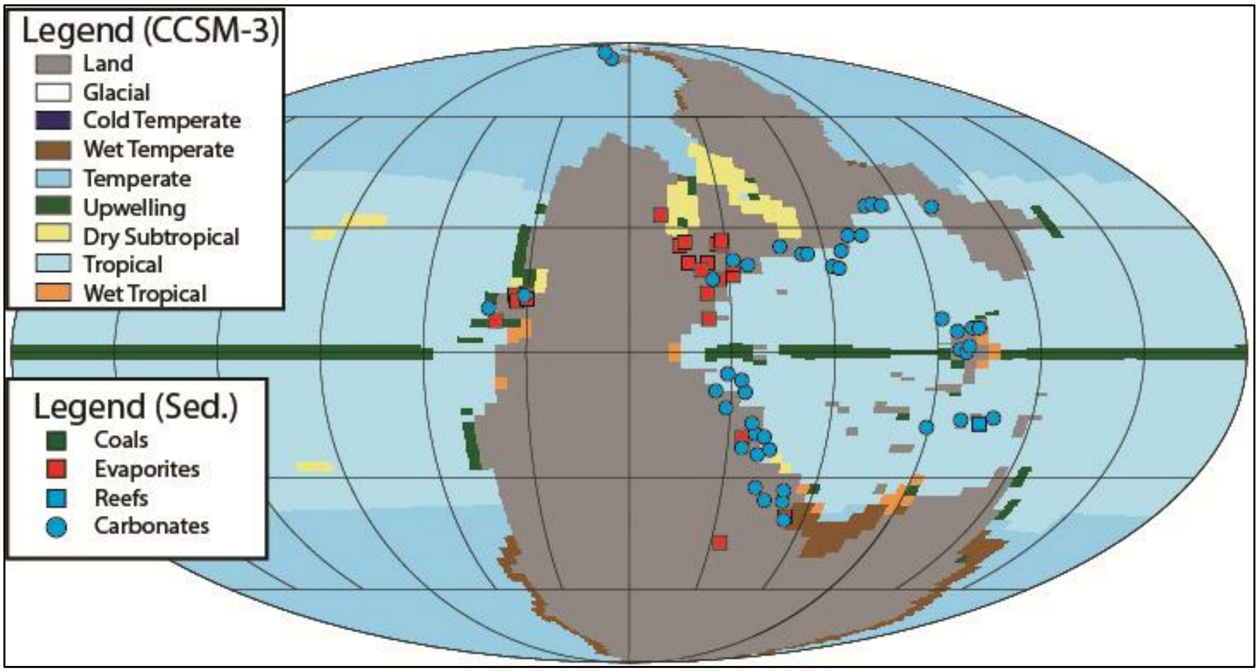

Figure 3: Comparison of marine climate zones from CCSM3 with geologic data from the Induan (Ziegler et al., 2003). Colors from the CCSM3 represent different climate regimes, with land being gray.

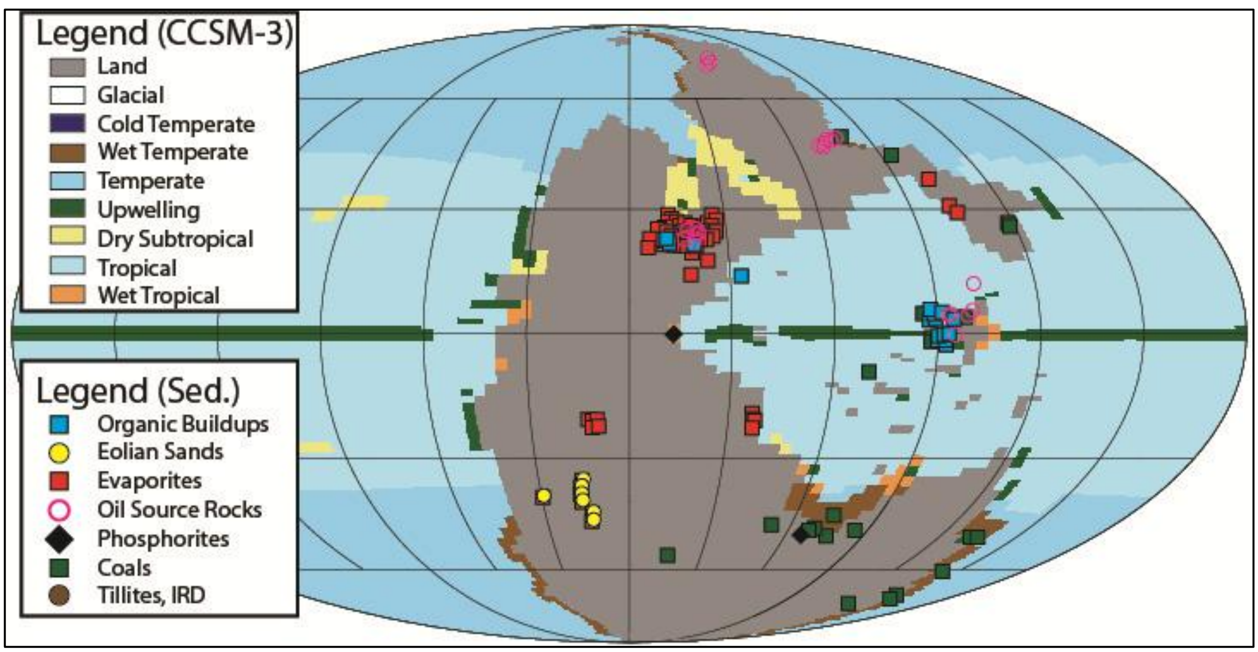

Figure 4: Comparison of marine climate zones from CCSM3 with geologic data from the Changhsingian (Ziegler et al., 1998). Colors from the CCSM3 represent different climate regimes, with land being gray.

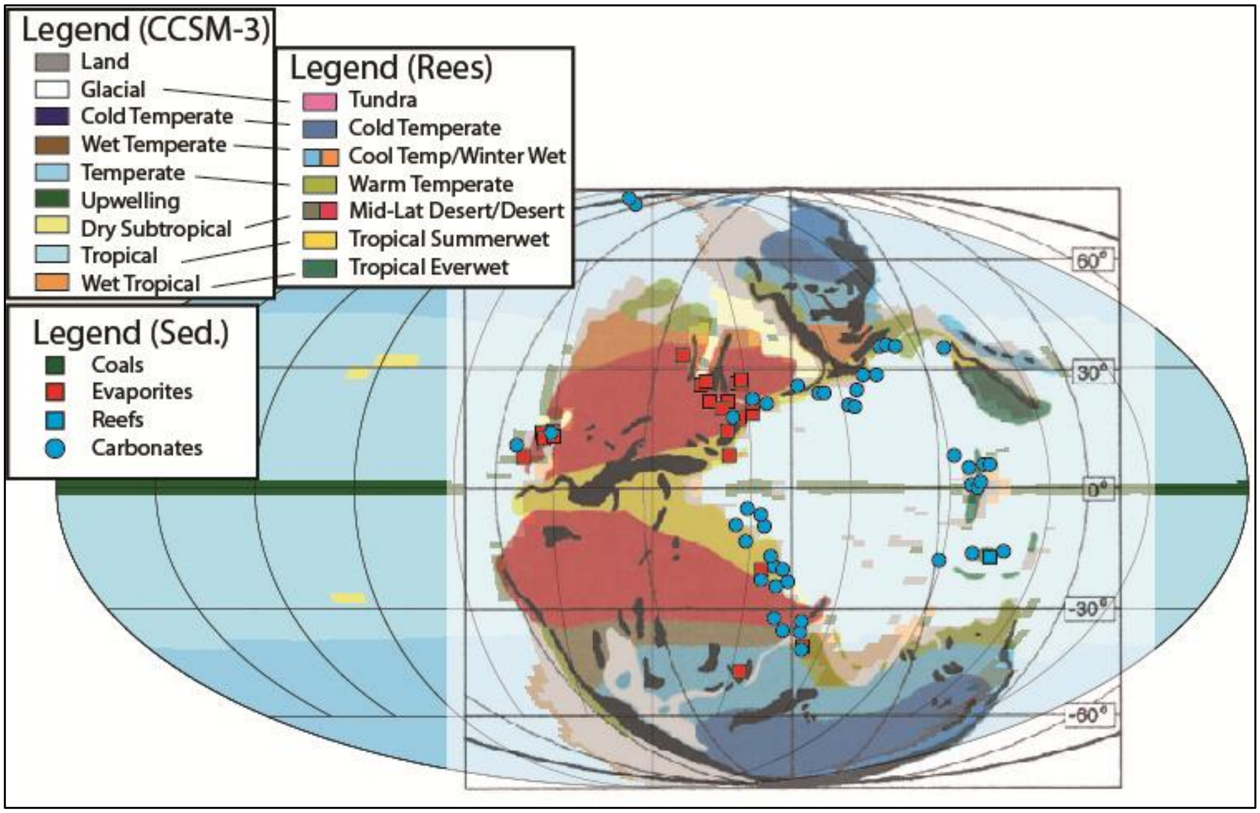

Figure 5: Comparison of modeled marine climate zones from CCSM3 along with modeled terrestrial climate zones based on Rees et al. (2002) in comparison with geologic data from the Induan Stage (Ziegler et al., 2003). Colors from the CCSM3 and Rees et al. (2002) represent different climate regimes.

Induan	Evaporites	Carbonates	Reefs
Total Points	22	45	1
Hits	19	33	1
Misses	3	12	0
% Correlation	86.36%	73.33%	100%

Table 3: "Hit-Miss" correlation analysis for the Induan Stage based on (Figure 5) and (Table 2)

Changhsingian	Coals	Evaporites	Phosphorites	Eolian Sands	Organic Buildups
Total Points	22	62	2	7	16
Hits	18	56	0	7	13
Misses	4	6	2	0	3
% Correlation	81.81%	90.32%	0%	100%	81.25%

Table 4: "Hit-Miss" correlation analysis for the Changhsingian Stage based on (Figure 6) and (Table 2)

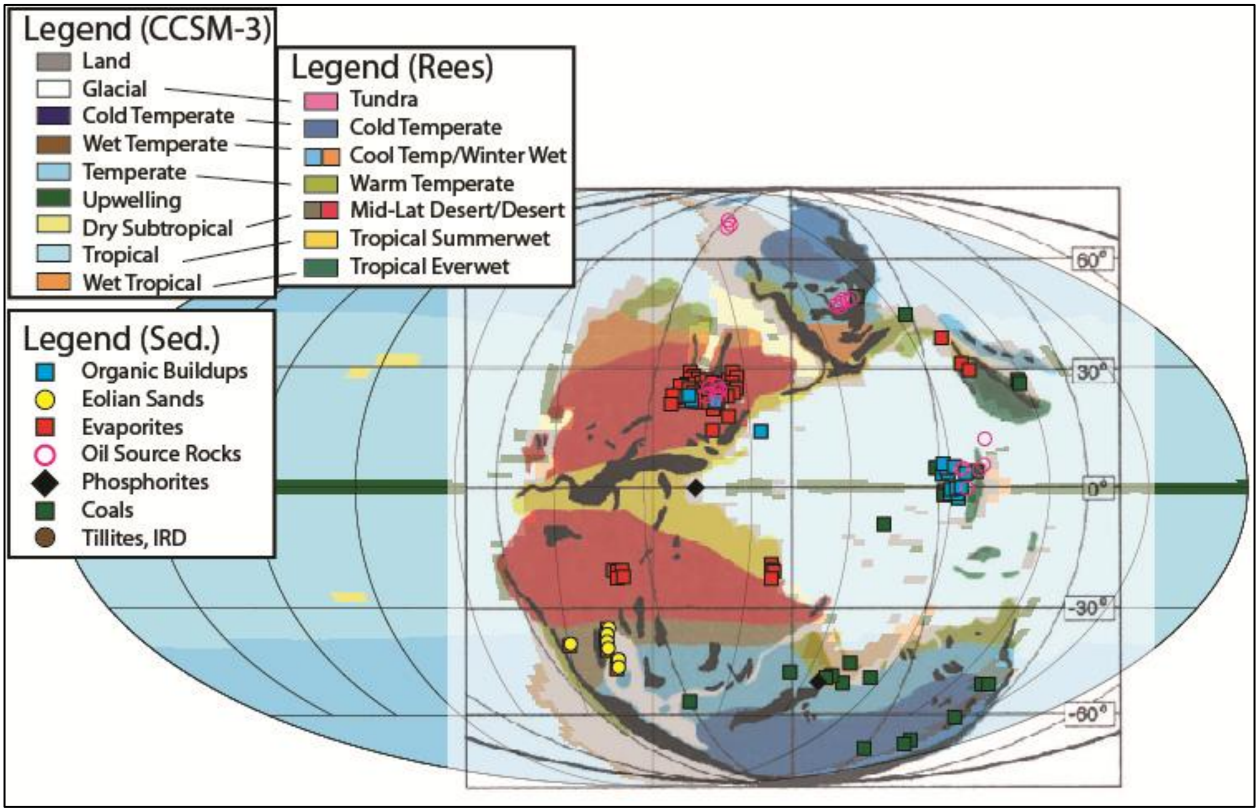

Figure 6: Comparison of modeled marine climate zones from CCSM3 along with modeled terrestrial climate zones based on Rees et al. (2002) in comparison with geologic data from the Changhsingian Stage (Ziegler et al., 1998). Colors from the CCSM3 and Rees et al. (2002) represent different climate regimes.

<u>Induan</u>	% Correlation from (Table 3)	95% Confidence Level Range
Evaporites	86.36%	(.720, 1.007)
Carbonates	73.33%	(.604, .862)
Reefs	100%	(1,1)

Table 5: The Induan Stage 1-proportion z interval test at a 95% confidence level.

<u>Changhsingian</u>	% Correlation from (Table 4)	95% Confidence Level Range
Coals	81.81%	(.657, .979)
Evaporites	90.32%	(.829, .976)
Phosphorites	0%	(0,0)
Eolian Sands	100%	(1,1)
Organic Buildups	81.25%	(.621,1.003)

Table 6: The Changhsingian Stage 1-proportion z interval test at a 95% confidence level.

DISCUSSION

The products of **(1)** a qualitative correlation of marine and terrestrial climate zones with geologic data, **(2)** a "hits" versus "misses" correlation analysis, **(3)** and a statistical correlation using a 1-proportion z-interval test at a 95% confidence level, yield helpful comparative conclusions in evaluating the modeled climate zones of the PTB.

(1) The qualitative comparison of marine climate zones from CCSM3 with geologic data for the Modern shows a strong correlation pattern which confirms that the model is working properly. Minor discrepancies occur in various geologic point categories, specifically in coals, where no pattern seems to exist, but could be explained due to regional climate regimes acting on the way sediment is being deposited, or the annual amount of rainfall per area. With these observations from the Modern, we can now apply the principle of uniformitarianism and discuss how well modeled Changhsingian, Induan, and Rees et al.'s (2002) Wordian climate zones correlate with geologic data from Ziegler et al. (1998, 2003).

A basic qualitative comparison of marine climate zones of the Modern versus the Induan and Changhsingian (**Figures 2-4**) show an absence of cold temperate and glacial regions signifying a warmer than average global temperature during the Permian-Triassic and a shift of the tropical and temperate zones to higher latitudes. The Induan marine climate zones compare moderately well with geologic data when evaluating qualitatively (**Figure 3**). There are only three geologic data types available to compare during this stage; evaporites, carbonates, and reefs. The three types appear to have consistency in their distribution with the Permian marine climate model zones. Carbonate and reef points correlate well with the tropical zone, but two of those points occur in the temperate zones high in the northern latitudes of the Induan Stage, suggesting either inaccurateness of geologic data positioning, or a potentially warm enough ocean to support a carbonate system at higher than normal latitudes. Evaporite evidence is sporadic throughout the Induan Earth, occurring both in the interior and at the margins of land masses, but is in agreement with the 30° latitude regime and the dry subtropical region of the Permian marine climate model zones, which is similar to the evaporite distribution of the Modern climate zones. One evaporite point within the Induan occurs roughly 15° south of the 30° southern latitude line, suggesting that regional climate dynamics like a rain shadow may have strongly affected climate in that area, or the dry subtropical region of the Induan may have had a greater expanse reaching farther than the normal 30° latitude. The idea of a dry subtropical expanse is intriguing and further investigation of Hadley cell dynamics would need to be pursued in order to understand the potential.

In the Changhsingian there are six geologic data types available to correlate with the PTB marine climate model zones, of which most fall within the landmass and not the ocean (**Figure 4**). Looking specifically at the PTB marine model versus geologic data, there is moderate correlation. Organic buildup points fall within the tropical zone, with a few points on land near a dry subtropical area. Eolian sands appear in the southern interior landmass, indicating a dry region where there is possibility of rain shadow climate occurring. Evaporites consistently occur near 30° latitude, similar to the distribution of Modern evaporites, but with a majority of landmass located on this latitude, effects of dry subtropical regions are more pronounced as indicated by the amount of dry subtropical marine climate zone area near the mid-northern landmass of the Changhsingian. The evaporite evidence seems overwhelming in this area and suggests a very arid warm climate during the period. Oil source rocks occur throughout the northern hemisphere and do not associate well with any particular climate zone, nevertheless it is interesting to find two oil source points in high latitude during this stage, indicating the absence of glaciers. With only two phosphorite points available, little correlative understanding can be drawn. Coal points reside within or near the temperate regions of the Permian marine climate model zones, but some points are found at equatorial latitude in the tropical zone indicating a potentially different mechanism of deposition may have been occurring. With the absence of tillites, it is likely that there were no continental glaciers present during the Changhsingian.

A majority of geologic points lay within the terrestrial areas rather than in the marine areas during the two time periods, and it is not possible to say with certainty the degree of qualitative correlation between the marine climate model CCSM3 and geologic data. Due to this issue, the terrestrial model of climate zones based on biome data of the Wordian Stage from Rees et al. (2002) was used to aid in qualitative as well as quantitative analysis in this study. Their study integrated biome data with lithological data to interpret terrestrial paleoclimates by applying a multivariate statistical analysis. Their study focuses on the Wordian Stage, roughly 14 million years before the PTB, and therefore does not match up as well with the PTB marine climate model zones we produced for the Changhsingian and Induan stages. It would be beneficial for future studies to have both terrestrial and marine climate zones from the same model and time period to make these correlations.

Using the terrestrial model of climate zones (Rees et al., 2002) overlain onto the PTB marine climate model zones results and geologic data, it becomes clear during the Induan there is strong correlation (**Figure 5**)**.** Carbonate and reef points appear to match up well within tropical zones of Rees et al. (2002), with a few points appearing in the desert zone and in the high northern cold temperate zone. These points could be in the wrong places due to regional effects on climate could suggest a very warm time period more widely, where carbonates and reefs could exist at higher latitudes than previously thought. Evaporite points match up consistently with the modeled terrestrial climate zones, except for one or two points which fall within temperate zones and not in the expected dry subtropical zone.

Modeled terrestrial climate zones from Rees et al. (2002) overlain onto the PTB marine model results and geologic data from the Changhsingian show strong correlation (**Figure 6**). Some organic buildup points appear to occur within the desert zone of the modeled terrestrial climates, but also occur in the expected tropical ever wet zones. Eolian sand occurrences align well with the mid-latitude desert zone and appear to be due to a rain shadow effect. Evaporite points are the most pronounced comparative indicator for this stage, correlating well within the terrestrial desert climate zone, mainly near 30° N, with a few points occurring in temperate to tropical regions. Coal points correlate well to the cool temperate and cold temperate regions, with a few discrepant points occurring in in the tropical ever wet zone in the middle Tethys, perhaps indicating that a different mechanism of coal deposition may have been occurring.

(2) The “hit” versus “misses” analysis produced strong correlation results (**Table 3**). This analysis was used with the PTB marine model and the terrestrial model from Rees et al. (2002). In the Induan there were a total of 22 evaporite points and, 19 of those “hit” within the predicted climate zone. This provided a correlation of 86.36%. Carbonates had a total of 45 points, 33 of those points “hit” and 12 “missed” the specified climate zones. This provided a correlation of 73.33%. With only 1 reef point, which “hit”, the data showed 100% correlation, although the reproducibility of this match cannot be confirmed with only a single point. These high percentages indicate that the modeled climate zones were generally consistent with the geologic data.

The Changhsingian showed similar results with strong correlation (**Table 4**). There were 22 coal points and 18 “hit” within the specified zones; 4 “missed”. This was a correlation of 81.81%. Out of 62 evaporite points, 56 “hit” and 6 “missed”, giving 90.32% correlation. The evaporite category may be the best indicator of accuracy for the time period because of the high number of data points available. Phosphorites only had 2 points and neither point “hit”, leaving a correlation of 0%. Eolian sands had similarly few data points, but “hit” on all points within the specified zone, giving 100% correlation. Organic buildups had 16 points and 13 “hit”, 3 “missed”, giving 81.25% correlation. Not considering phosphorites or eolian sands because of their rarity, the other 3 geologic categories suggest strong correlation.

(3) The 1-proportion z-interval test at a 95% confidence level yielded results that correlate well. The statistical test results (**Tables 5-6**) provide a percentage range. Higher ranges indicate that the null hypothesis (random correlation) is considered falsified and that the geologic data points do not occur randomly, but rather have a pattern to their position within the modeled climate zones. Looking at the Induan results of this method (**Table 5**), evaporite points have a range of more than (.72, 1.007), meaning that a high percentage of geologic data points will fall within the correct zone specified based on **Table (2)**. Carbonates have a range of (.604, .862), which is not as good as evaporites but still on the high end.

The Changhsingian statistical ranges (**Table 6**) are even better than the Induan. Coals and evaporites have ranges of (.657, .979) and (.829, .976), respectively. With the ranges and number of points being so large for evaporites in the Changhsingian and Induan, these data points may be considered the strongest support for a good match between climate model results and geologic data. Finally, organic buildup points had a larger range (.621, 1.003), indicating strong correspondence. This z-interval test is a more accurate test to determine whether the model is providing reliable reconstructions of climate zones, therefore providing a greater understanding of past climate.

CONCLUSIONS

This study aimed to determine how well climate reconstructions of the PTB compare to the geologic record. Our findings indicate that there is a strong correlation between the two and that the CCSM3 model, along with the terrestrial climate model (Rees et al.'s, 2002) are viable reconstructions of paleoclimate. The average statistical 95% confidence level range throughout the Changhsingian and Induan Stage ages was (.6788, .8533). Overall, the Permian climate models are a good fit to known geologic climate indicators. With confidence in the model results, we can improve understanding of the factors that influenced PTB paleoclimate. In addition, paleoclimate model output can be used to constrain hypotheses regarding the role of climate in driving the end-Permian mass extinction.

REFERENCES CITED

Algeo, T.J., Hinnov, L., Moser, J., Maynard, J.B., Elswick, E., Kuwahara, K., Sano, H., 2010, Changes in productivity and redox conditions in the Panthalassic Ocean during the latest Permian: Geology, v. 38, p. 187-190.

Erwin, D.H., 2006, Extinction: How life on earth nearly ended 250 million years ago, Princeton University Press, Princeton, New Jersey.

Isozaki, Y., 1997, Permo-Triassic boundary superanoxia and stratified superocean: records from Lost Deep Sea: Science, v. 276, p. 235-238.

Kiehl, J.T., and Shields, C.A., 2005, Climate simulation of the latest Permian: implications for mass extinction: Geology, v. 33, no. 9, p. 757–760.

Mayfield, P., 2011, Understanding binomial confidence intervals, accessed 1 May 2012, http://www.sigmazone.com/binomial_confidence_interval.htm.

Montenegro, A., Spence, P., Meissner, K.J., Eby, M., Melchin, M.J., and Johnston, S.T., 2011, Climate simulations of the Permian-Triassic boundary: ocean acidification and the extinction event: Paleoceanography, v. 26, p. 1-19.

Mundil, R., Ludwig, K.R., Metacalfe, I., and Renne, P.R., 2004, Age and time of the end Permian mass extinctions: U/Pb geochronology on closed-system zircons: Science, v. 305, p. 760-765.

Parrish, J.T., 1993, Climate of the supercontinent Pangea: The Journal of Geology, v. 101, p. 215-233.

Rees, P.M., Ziegler, A.M., Gibbs, M.T., Kutzbach, J.E., Behling, P.J., and Rowley, D.B., 2002, Permian phytogeographic patterns and climate data/model comparisons: The Journal of Geology, v. 110, p. 1-31.

Scotese, C.R., 2003, Paleomap Project, accessed 16 April 2012, http://www.scotese.com/newpage5.htm.

Twitchett, R.J., Looy, C.V., Marante, R., Visscher, H., and Wignall, P., 2001, Rapid and synchronous collapse of marine and terrestrial ecosystems during the end-Permain biotic crisis: Geology, v. 29, p.351-354.

Winguth, A.M.E., Heinze, C., Kutzbach, J.E., Maier-Reimer, E., Mikolajewicz, U., Rowley, D., Rees, A., and Ziegler, A.M., 2002, Simulated warm polar currents during the middle Permian: Paleoceanography, v. 17.

Ziegler, A.M., Gibbs, M.T., and Hulver, M.L., 1998, A mini-atlas of oceanic water masses in the Permian period: Proceedings of the Royal Society of Victoria, v. 110(1/2), p. 323-343.

Ziegler, A.M., Eshel, G., McAllister Rees, P., Rothfus, T.A., Rowley, D.B., and Sunderlin, D., 2003, Tracing the tropics across land and sea: Permian to present: Lethaia, v. 36, p. 227-254.