CHARACTERIZING THE PHANEROZOIC STRATIGRAPHIC ARCHITECTURE OF EUROPE USING SLOSS-TYPE SEQUENCES

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ABSTRACT

Sequences are defined as discrete packages of sedimentary rock bounded by interregional erosional surfaces, making them ideal stratal units for regional stratigraphic study. We present a new continental-scale study of the six Sloss-type sequences across Europe, with emphasis on stratigraphic architecture.

Details of the sediments across Europe, including offshore shelf regions, were compiled into 481 stratigraphic columns using available publications, seismic data, and well records. RockWorks 17 software was used to track sequence boundaries, lithologic data, and locations. A three-dimensional lithology model, isopach maps, stratigraphic profiles and basal sequence lithology maps were created for each of the six sequences.

Results show that siliciclastics dominated deposition in the earliest two sequences (Sauk and Tippecanoe) and again in the last sequence, the Tejas. The earliest two sequences also had the least extent, with surface coverage of just over 5 million km^2 for both the Sauk and the Tippecanoe. Deposition of the Sauk and Tippecanoe was primarily limited to selected locations in westernmost Russia, north-central Europe and the Iberian Peninsula. The volume of siliciclastics in the earliest three sequences fluctuated between 2 and 4 million km^3. In contrast, the volume of siliciclastics increased markedly in the Absaroka, ballooning to 15.5 million km^3. The subsequent Zuni sequence shows a decrease in siliciclastic volume (8.9 million km^3) before another large increase is observed in the Tejas sequence (14.1 million km^3). In fact, siliciclastic deposition within Tejas was the highest in terms of percentage by volume at 74.9%.

Carbonate deposition reflected an inverse relationship to the siliciclastic patterns. Only the Kaskaskia sequence shows a dominance of carbonate deposition by volume at 52.9%. The relative amount of carbonate deposition then decreased in the later Absaroka sequence to 29.1%, whereas the actual volume of carbonate deposited showed an increase from 5.5 million km^3 in the Kaskaskia to 7.7 million km^3 in the Absaroka. The Kaskaskia, Absaroka and Zuni sequences all show relatively similar volumes of carbonate deposition, varying from 5.5 to 7.7 million km^3. In contrast, the Sauk, Tippecanoe and Tejas all have carbonate depositional volumes at or less than 2.1 million km^3.

INTRODUCTION

Sequences are defined as discrete packages of sedimentary rock bounded top and bottom by erosional surfaces, often with coarse sandstone layers commonly at the base (Sloss, 1963). A transgressive surface of marine erosion (TSE) marks the base of most Sloss-type sequences, representing the base of a rapid transgressive tract. Whereas, a maximum flooding surface (MFS) marks the top of each Sloss sequence, representing the maximum sea level highstand.

Subsequent sequences formed as sea level repetitively rose and fell, resulting in flooding of the North American continent up to six times in the Phanerozoic (Sloss, 1963; Haq et al, 1988). Upper erosional boundaries were created as each new sequence eroded the top of the earlier sequence as it advanced. The sequences stack one on top of each other as shown in Fig. 1. Similar sequences have been correlated to South America and Europe (Soares et al., 1978) (Fig. 2). These same sequence boundaries were assumed to be present in Africa as South America and Africa were one land mass up until the Cretaceous.

Well log, seismic data and biostratigraphic data allow correlation of the upper (MFS) and lower (TSE) unconformity bounding surfaces for each sequence across the European continent. We created a three-dimensional, sequence-by-sequence, stratigraphic model using vertical stratigraphic columns across Europe. Available well logs, outcrop and seismic data were utilized in the construction of the rock columns.

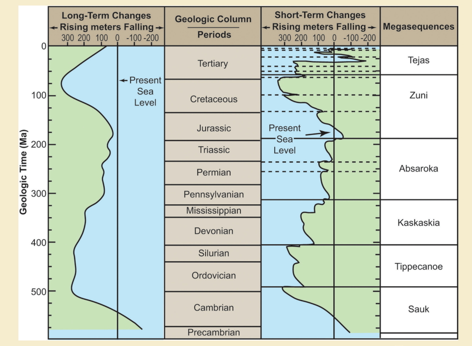


Figure 1

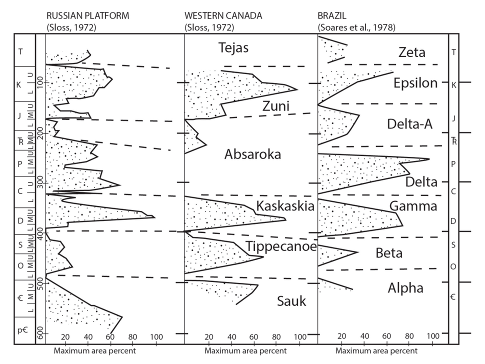


Figure 2

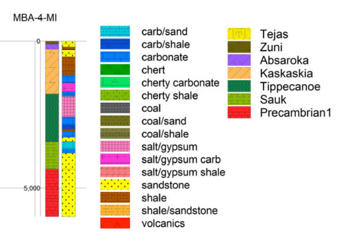


Figure 3

METHODS

We used numerous well logs, outcrops and seismic data from hundreds of available online sources to construct 499 stratigraphic columns across Europe, Turkey, and the Caucasus, from the pre-Pleistocene down to local basement. We input detailed lithologic data, sequence boundaries and latitude and longitude coordinates into RockWorks 17, a commercial software program for geologic data, available from RockWare, Inc. Golden, CO, USA. Fig. 3 is an example stratigraphic column showing the 16 types of lithology that were used for classification and the sequences. Depths shown in all diagrams are in meters.

A graphics program in RockWorks 17 allowed us to record the basal lithology in each sequence. We assumed the basal lithologic unit was the best preserved in the transgressive/regressive depositional/erosional cycle. We then trimmed the computer-generated isopach maps to match the extent of each sequence shown by the basal lithology maps.

RockWorks 17 was used to calculate models of the thickness of each stratigraphic unit, and the maximum extent maps were used to constrain the thickness models. The adjusted thickness models were then used along with column data to create 3-dimensional models and volume estimations of the lithology for each stratigraphic sequence. The total rock volumes are shown in Fig. 4, sequence by sequence. All volume data are recorded in cubic kilometers.

Total Sediment by Sequence

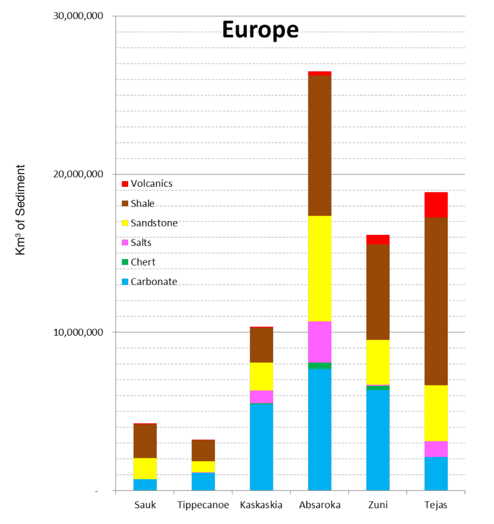
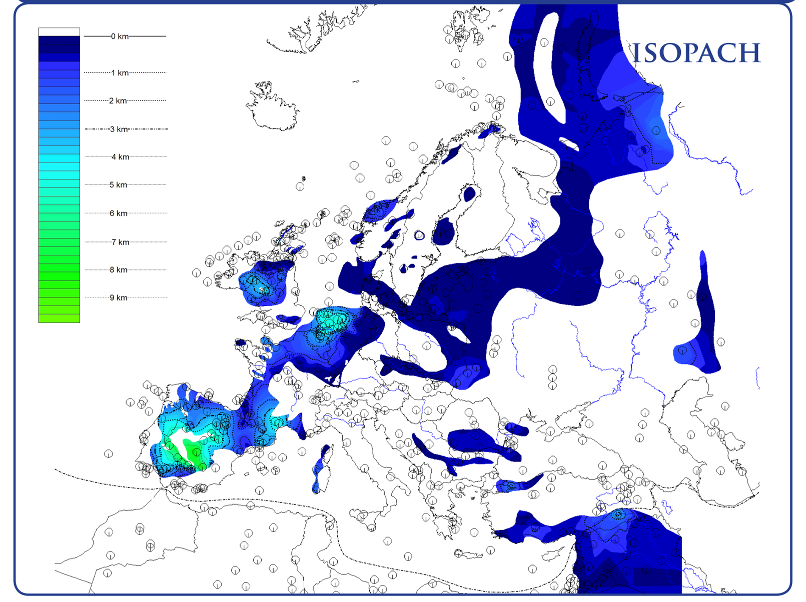
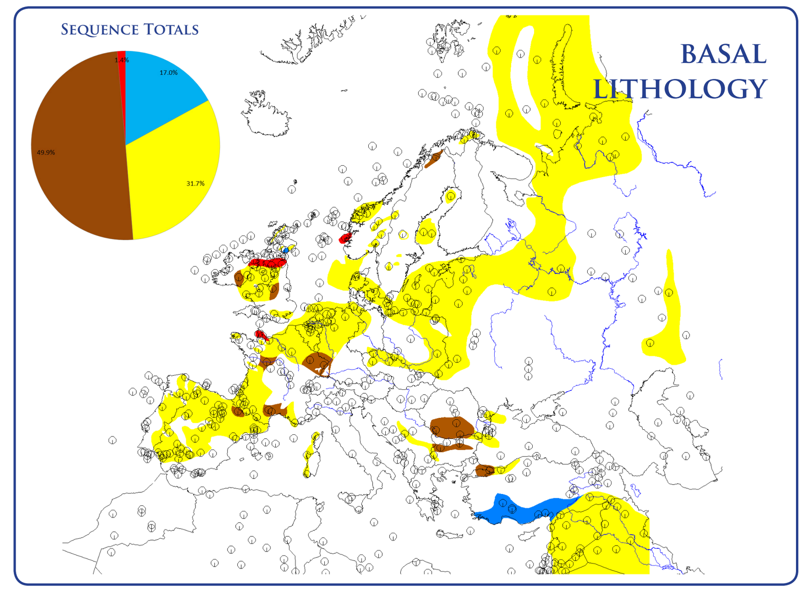
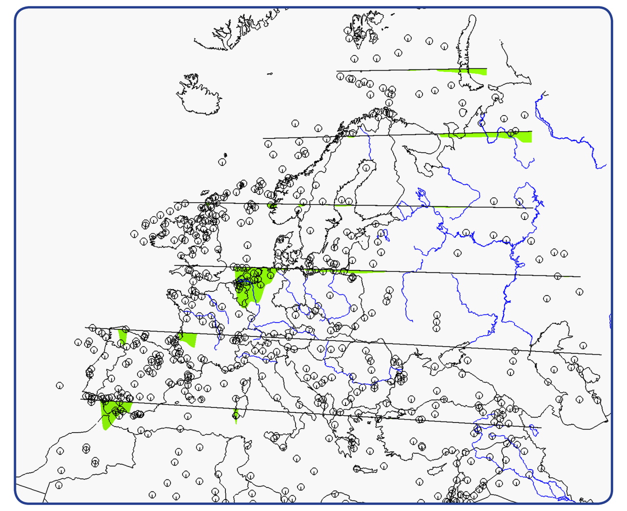


Figure 4

Sauk



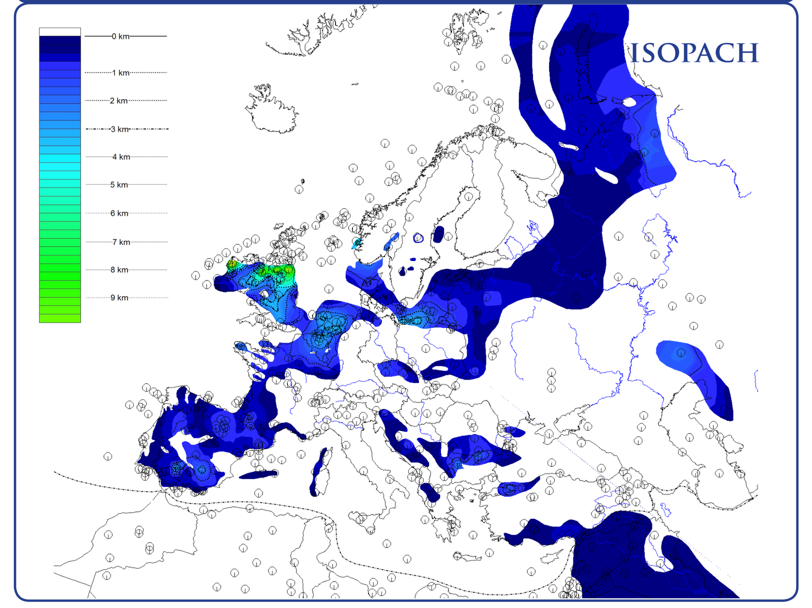


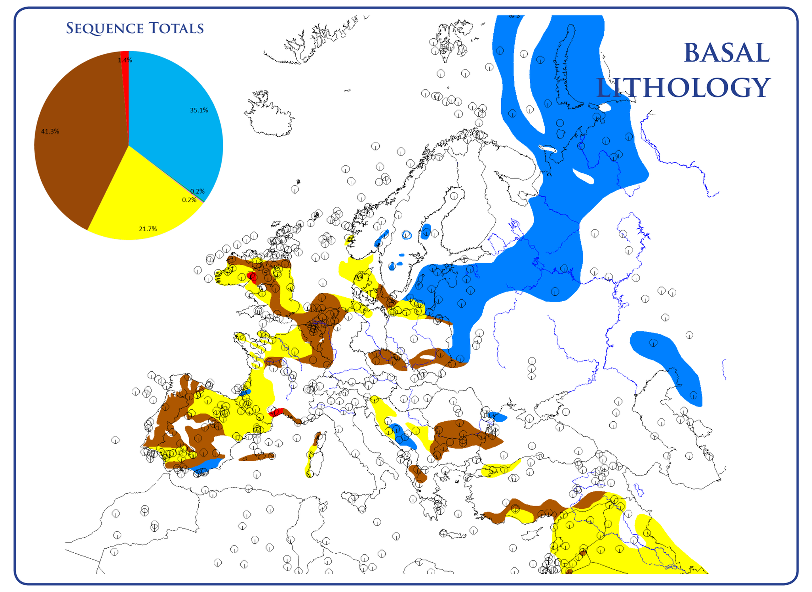


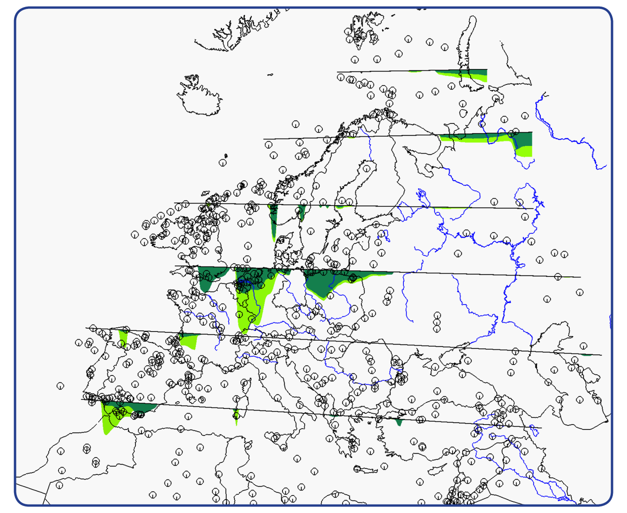
Results 1: Sauk Sequence

The Sauk sequence extends from the Cambrian to the Early Ordovician System. The base of this sequence consists primarily of a mixed sand and shale unit extending across Europe in the northwest. The Sauk reaches a depth of over 7 km in Spain, but its average thickness is only 825 m. The Sauk is the least extensive sequence in Europe by surface area. Siliciclastics are the dominant rock type in the Sauk at 82% of total volume.

Tippecanoe



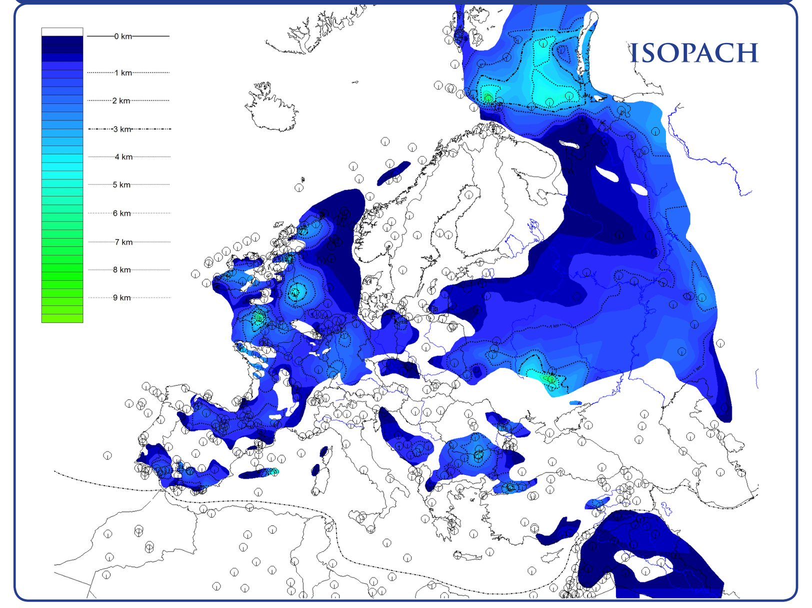


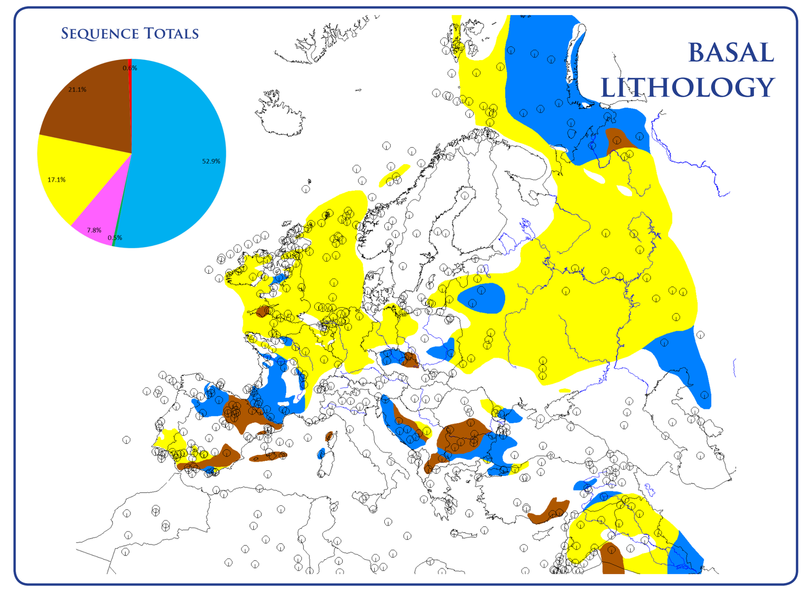


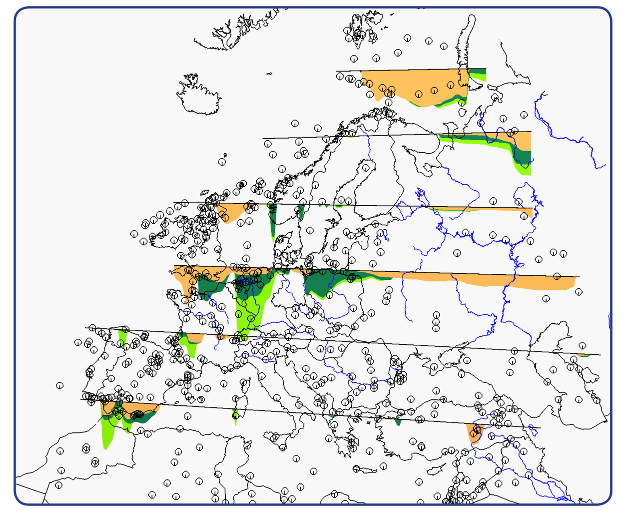
Results 2: Tippecanoe Sequence

The Tippecanoe sequence extends from the Middle Ordovician to the top of the Silurian System. The base of this sequence is mostly sand and shale in the west and south, but consists primarily of limestone in the Baltics and Russia. Siliciclastics are the majority rock type in the Tippecanoe at 63% of total volume. The Tippecanoe is the thinnest sequence in Europe, at an average of 620 m thick. The Tippecanoe and Sauk together comprise less than 10% of the total volume deposited by all six sequences.

Kaskaskia



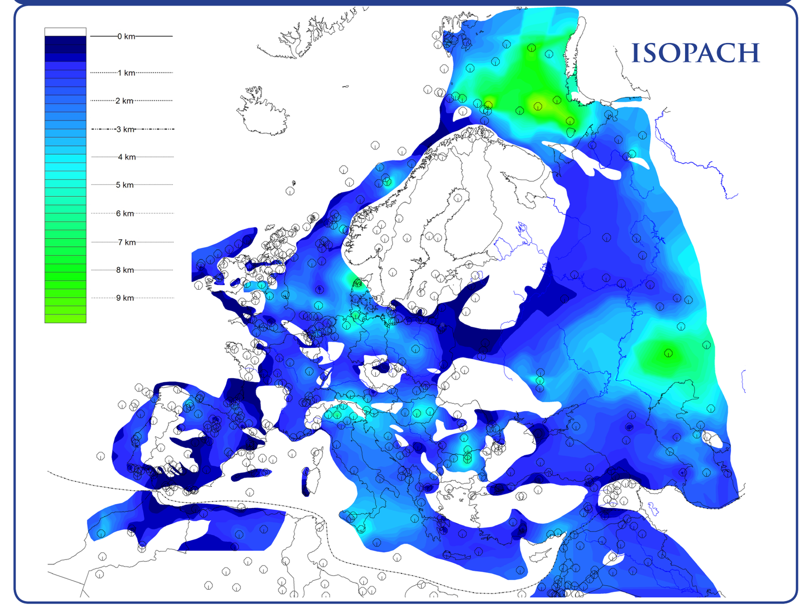


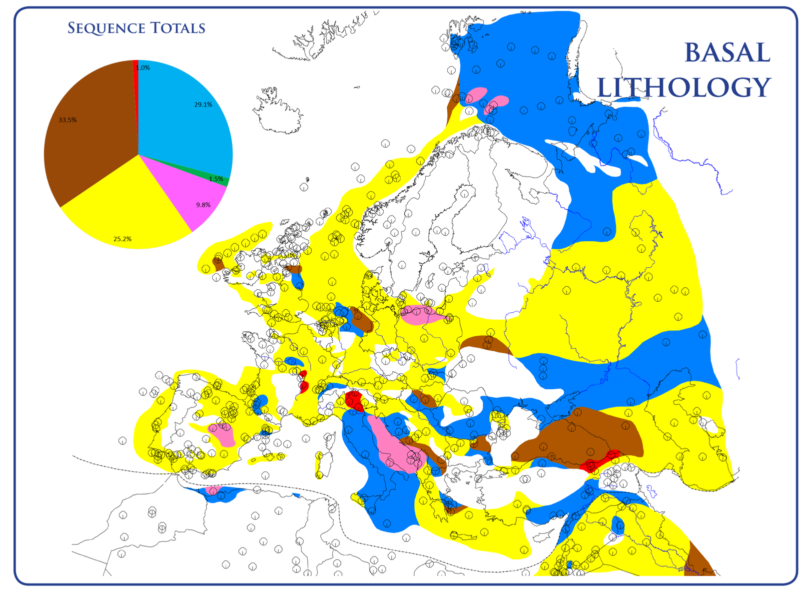


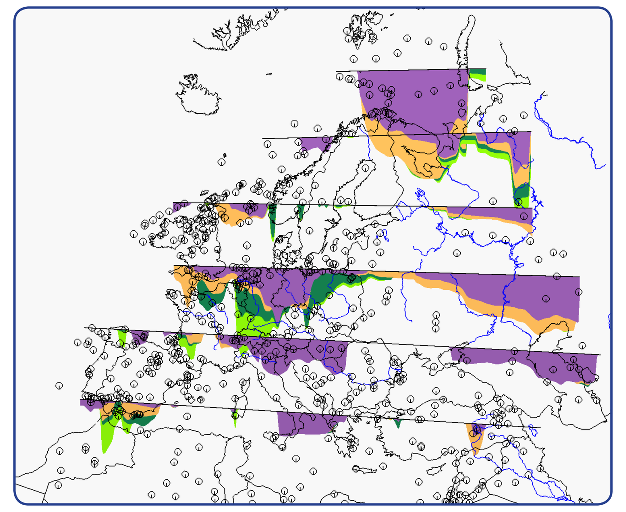
Results 3: Kaskaskia Sequence

The Kaskaskia sequence extends from the Devonian to the top of the Mississippian System. The base of this sequence is mostly a sand and shale mix, with scattered basal deposits of limestone. However, by percentage of volume the Kaskaskia contains the most carbonates and the least siliciclastics, at 53% and 38% respectively. The Kaskaskia is significantly larger than the previous sequences. Its volume (13% of total deposition) is roughly twice as thick as the Tippecanoe, and it covers about 1.5x more surface area. This is mostly due to increased deposition in the North and Barents Seas and the East European Plain.

Absaroka



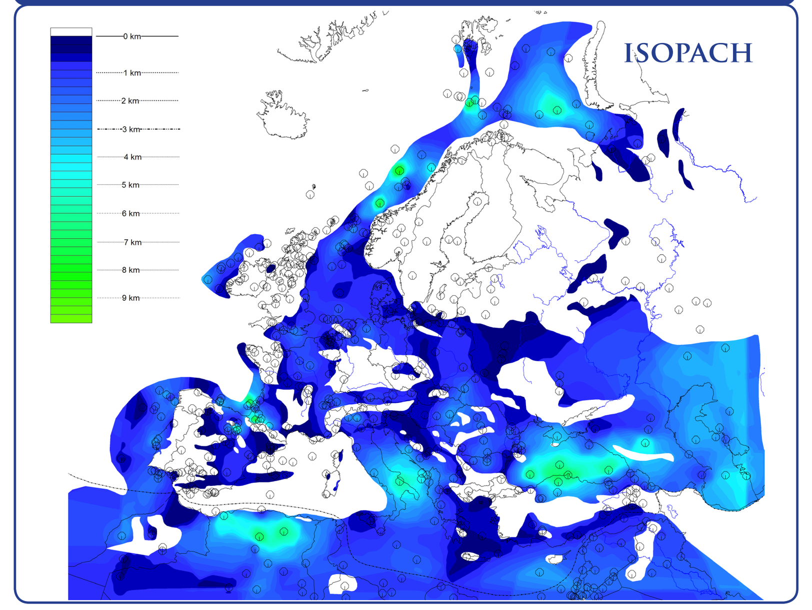


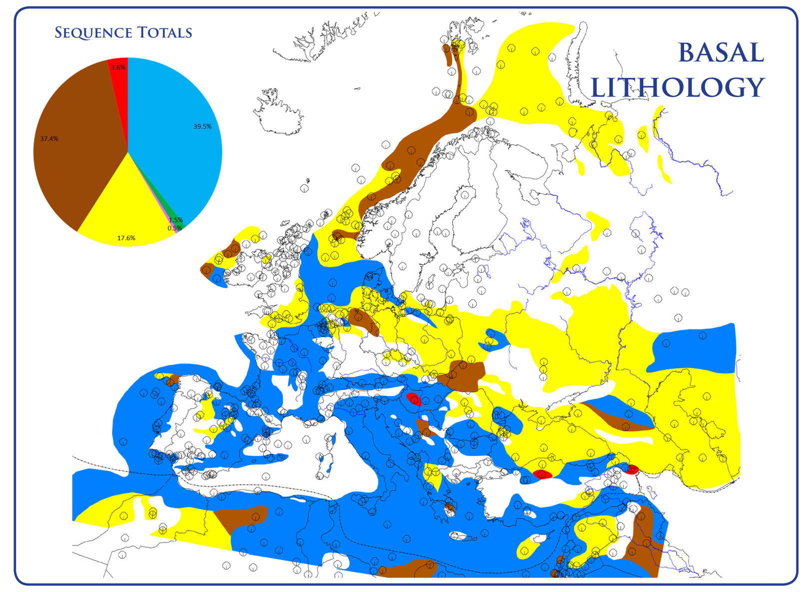


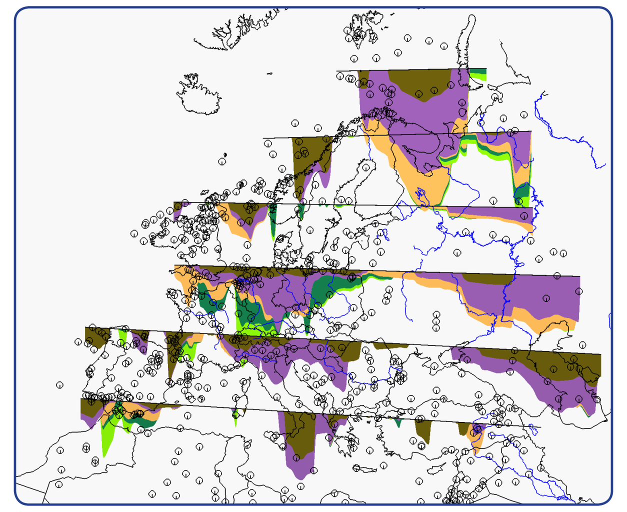
Results 4: Absaroka Sequence

The Absaroka sequence extends from the Pennsylvanian to the Lower Jurassic System. This sequence consists of 58% siliciclastics and has the highest percentage of salt and gypsum deposits (10%) of the six sequences. This sequence marks the first deposits in the Italian peninsula, the offshore Mediterranean Sea, and the Atlantic Ocean outside of the North Sea. The Absaroka is the most voluminous (34% of total deposition), the most extensive, and the thickest sequence (2.3 km on average) in Europe.

Zuni



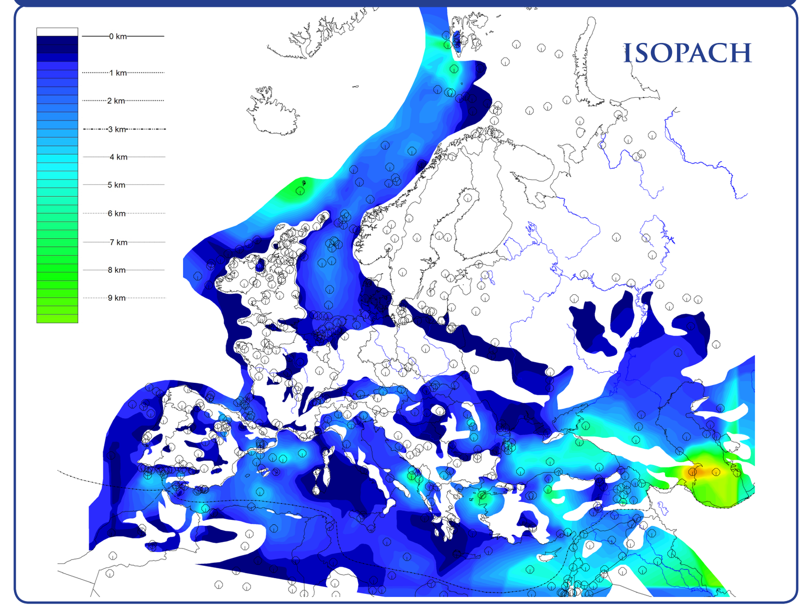


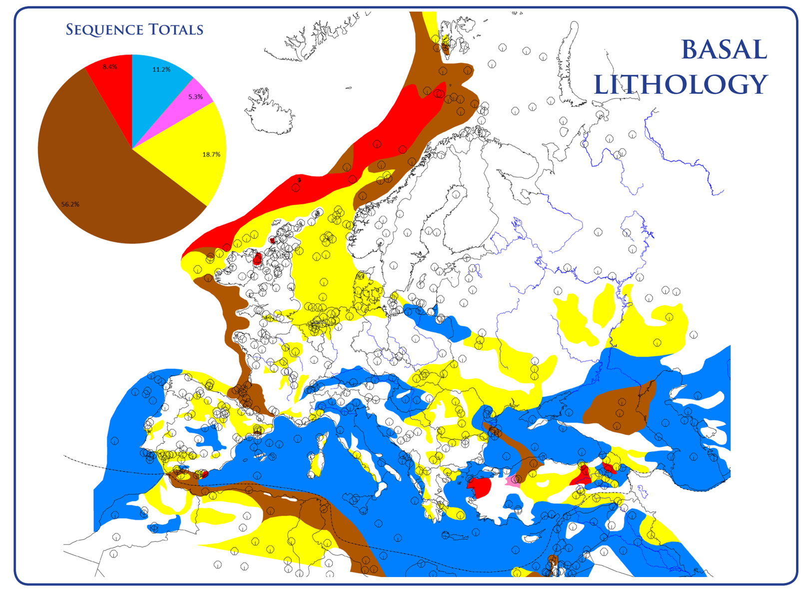


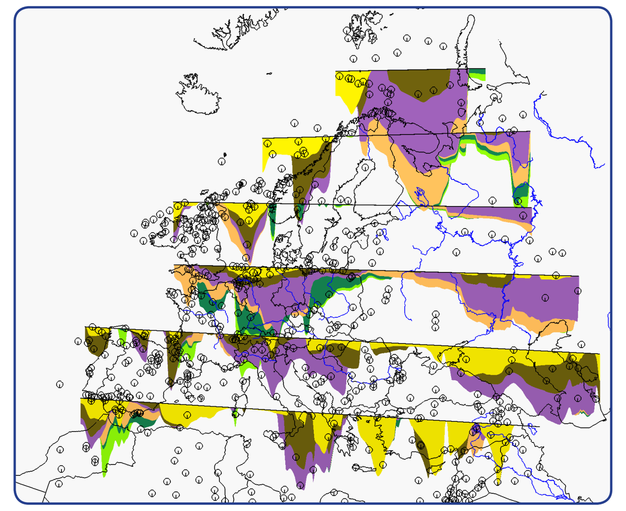
Results 5: Zuni Sequence

The Zuni sequence extends from the Middle Jurassic to the lowermost Paleogene System (slightly post Cretaceous). Much of the base of this sequence consists of limestone deposits, and on the whole carbonates make up 39% of the total volume of the Zuni. This sequence shows an overall offshore trend. Along with a noticeable decrease in deposition in the East European Plain, major deposition is seen in the Atlantic Ocean and the Mediterranean, Black, and Caspian Seas. The Zuni has an average thickness of 1.6 km, and is 20% of total deposition.

Tejas







Results 6: Tejas Sequence

The Tejas sequence extends from near the base of the Paleogene System to the top of the Neogene. Even though the base of this sequence across the south of the area of study is a thin limestone layer, the Tejas is the least carbonaceous of the six sequences, consisting of only 11% carbonate by volume and 75% siliciclastics. The thickest deposits of Tejas sediment occur offshore. The Tejas accounts for 24% of the total deposition of the six sequences, and has an average thickness of 2.0 km.

CONCLUSIONS

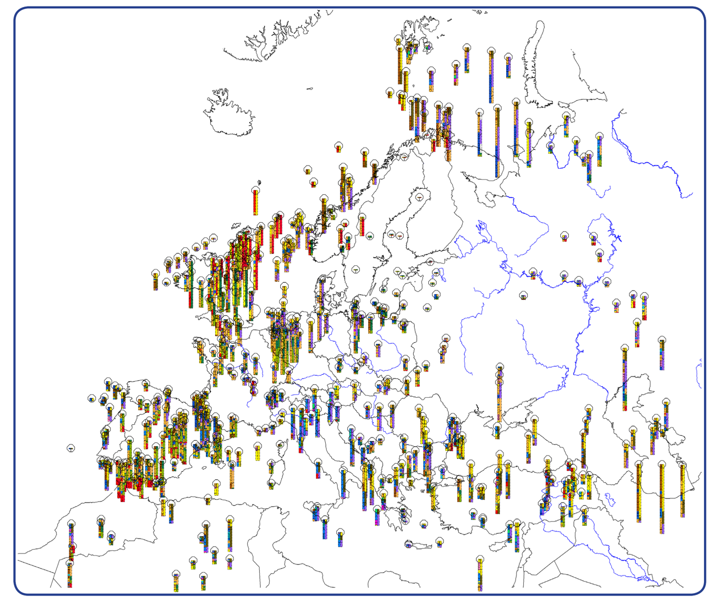
Five of the six Phanerozoic sequences across Europe are composed predominantly of siliciclastics, with carbonate only playing a dominant role in the Kaskaskia sequence. Salt and gypsum-rich rocks make a significant contribution to both the Kaskaskia and Absaroka (Zechstein salt) sequences and to a lesser extent the Tejas (Miocene event in the Mediterranean Sea). Oddly salt and gypsum never make a substantial contribution to the rocks of the other three sequences by volume.

The two earliest sequences (Sauk and Tippecanoe) have both the least volume and the least surface area extent. Successive sequences show a substantial increase in both volume and surface coverage. The Sauk sequence begins with a modest volume of just over 4 million km^3 and the Tejas sequence ends with a volume of almost 19 million km^3 (Fig. 4). The largest jump in deposition from one sequence to the next was from the Kaskaskia (just over 10 million km^3) to the Absaroka (over 26 million km^3).

The dramatic increase in the volume of sediment deposited in the Absaroka sequence is likely linked to the change in plate tectonic activity that occurred at this junction, in particular the formation of the Mid-Atlantic ridge west of Europe. The addition of significant volumes of strata on the newly-formed Atlantic continental shelf likely contributed greatly to this abrupt increase. The Absaroka also marked the first significant deposition across much of the Mediterranean Sea and parts of southern Europe. These new locations of deposition may explain why the Absaroka sequence is the most extensive and most voluminous of all of the sequences.

Most global sea level curves indicate a high sea level prevailed during deposition of the Ordovician System (the late Sauk sequence and/or the Tippecanoe sequence) (Fig.1). However, the areal extent and small volume of sediment deposited across Europe during the Sauk and Tippecanoe sequences suggest a less extreme early Phanerozoic rise in sea level.

Column Data Summary



ACKNOWLEDGEMENTS

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