

Cretaceous Large Igneous Provinces (LIPs) Affect Sedimentary Processing: Jordan, Arabian Plate; NW Germany, Central Europe

Werner Schneider¹, Elias Salameh²

¹(Retired) Department of Geology, Faculty of Science, Braunschweig Technical University, Braunschweig, Germany

²Department of Geology, Faculty of Science, University of Jordan, Amman, Jordan

Email: salameli@ju.edu.jo

How to cite this paper: Schneider, W. and Salameh, E. (2024) Cretaceous Large Igneous Provinces (LIPs) Affect Sedimentary Processing: Jordan, Arabian Plate; NW Germany, Central Europe. *Open Journal of Geology*, 14, 671-704.

<https://doi.org/10.4236/ojg.2024.146029>

Received: May 25, 2024

Accepted: June 22, 2024

Published: June 25, 2024

Copyright © 2024 by author(s) and

Scientific Research Publishing Inc.

This work is licensed under the Creative

Commons Attribution-NonCommercial

International License (CC BY-NC 4.0).

<http://creativecommons.org/licenses/by-nc/4.0/>



Open Access

Abstract

Both the NE Gondwana Platform (Jordan) and the Carpathian/NW Europe Seaway towards the N Atlantic expose comparable sequence analytical patterns as *i.e.* the Maximum Flooding Surface (MSF), relating to the Arabian Shelf, throughout one of the warmest Phanerozoic Epochs. Supervolcanic Large Igneous Provinces (LIPs), (explosive island arc andesitic volcanism), Mid-Oceanic Rift Basalts (MORB), (S/N Atlantic, Arctic) and kimberlitic volcanism (W Gondwana) provided striking conditions for an immense influence (tuff, degassing, T) on the sedimentary processing throughout the Cretaceous, mainly verified by K-montmorillonite, dozens of tuff beds (predominantly in NW Germany), zeolite, cristobalite, extremely high chert occurrences as well as the reconfirming of the global anoxic event around the Cenomanian/Turonian b. (94 Ma) by a positive $\delta^{13}\text{C}$ -maximum (~0.5%). Thus the lithofacies spectrum (carbonate rocks, chalk, chert, porcellanite, shale) was affected by pH, Eh, T, photosynthesis, and greenhouse gases—change during varying positive/negative climate forcing. While acid sturzrain events caused the transformation of arkosic/subarkosic sediments of the hinterlands to quartz arenite cycles deposited on the Jordanian Platform during early Cretaceous, the other patterns mentioned, led to a rapid change of lithofacies through Late Cretaceous. The southward directed Neotethys transgression can be reconstructed during the Early Cretaceous by glauconite-aged tidalites that give hint on transpressional tectonics during the Upper Cenomanian east of the Dead Sea. The Cretaceous/Paleogene (K-Pg) transitional zone evidences a zone of several cumulative events (island arc-volcanism) and the Chicxulub impact, indicated by at least two extinctions phases. The southward obduction of the Palmyrides, Syria and related transtensional/transpressional strike slip tectonics (partially pull-apart structures) left a fast facies change on the Jordanian Platform.

Keywords

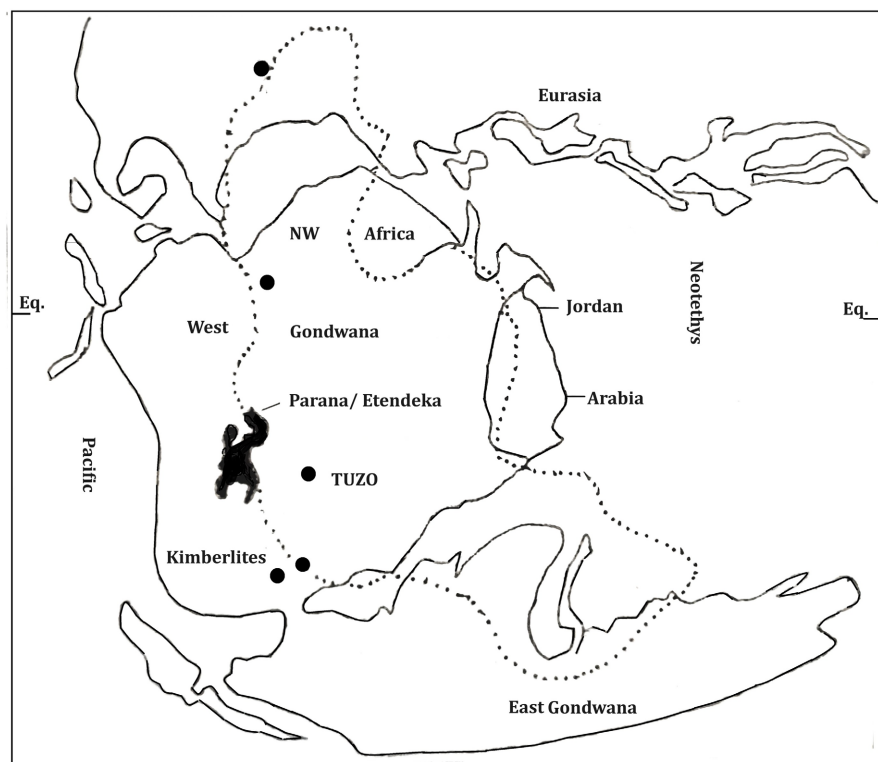
Degassing, Explosive Tuff, Acid Rain, Climate Forcing, Photosynthesis, Mineral Trans/Neoformation, Lithofacies Modified, Synsedimentary Tectonics

1. Introduction

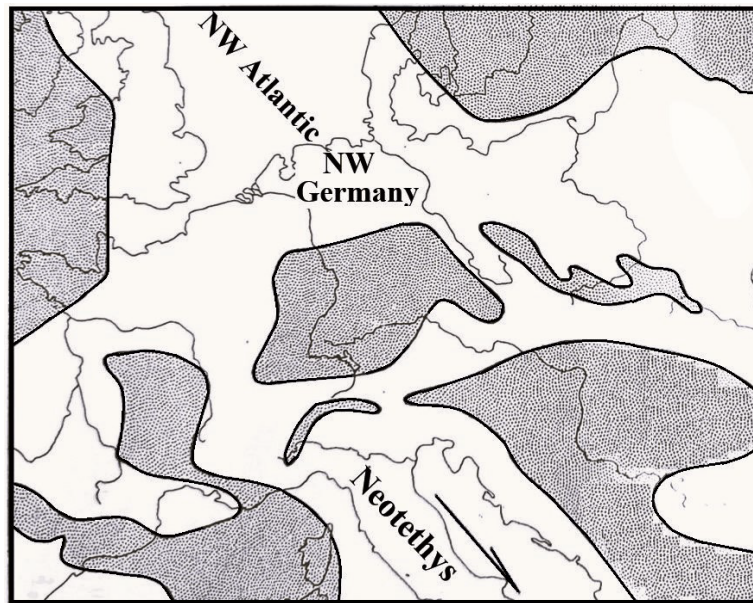
The opening of both the S- [1] [2] [3] [4] and the N- [4] [5] [6] Atlantic was accompanied by Mid-Oceanic Rift Basalts (MORB), oceanic basin development, subduction-related explosive island arc-volcanism, plate motion, anomalous long time-span of normal Earth magnetization ([7], ~125 - 85 Ma), and finally by a mantle plume [5] through the Cretaceous/Tertiary boundary (KPgB: ~66 Ma).

The Cretaceous sedimentary scenery developed under rising Earth surface temperatures ([7], ~115 - 90 Ma, 22°C - 24°C), growth rate of oceanic crust up to 10 km³/a ([7], ~125 - 75 Ma), maximum sea level rise/tidal dissemination (~100 - 66 Ma), high bio-calcification [7] [8] influenced by magmatic degassing and tuff eruptions via subsequent climate forcing [9].

Arabia belonged during the Lower Cretaceous to W Gondwana [10] and was located in the plume generation zone TUZO ([4] **Figure 1(A)**), while NW Germany, Central Europe was situated along the connecting route between the Tethys and the N Atlantic via the Carpathian seaway ([11] **Figure 1(B)**).



(A)



(B)

Figure 1. Geological setting of the study areas: (A) Position of Jordan at the NE-edge of the Arabian Plate, eastern part of W Gondwana and of the eastern plume generation zone TUZO at ~135 Ma, see the onset of the Parana/Etendeka LIPs ~134 Ma and kimberlite sites [4]. (B) Cenomanian paleogeography of NW Europe between Tethys and NW Atlantic via the Carpathian seaway [11].

Experienced by studies performed during the last decade on the Jordanian Platform, a complex interplay of both endogenous and exogenous forces was encountered throughout the Phanerozoic via climate forcing:

- Major magmatic events affected sedimentary architectural elements/lithofacies and sequence-analytical patterns [12].
- Environmental acidification by Large Igneous Provinces (LIPs) and rift-degassing directed the formation of several Phanerozoic quartz arenite sequences [13].
- The Siberian LIP caused complex sedimentologic-mineralogic-geochemical patterns throughout the Permian-Triassic transitional zone (PTB) [14] [15].
- Multiple impacting (Manicouagan, Rochechouart) and LIP-degassing in the Proto-Arctic (PAO) and Central Atlantic Magmatic Province (CAMP) had significant influence on Upper Triassic sedimentary processing [6] [16] [17] [18].
- Ordovician sedimentary processing was highly concerned by global subduction-related explosive island arc volcanism and minor impacting [19] [20] [21].

Since the Proterozoic, the transitional zone between the Arabian Plate and the Levant Block [22] has presented an area of latent weakness. Already during the Late Proterozoic, the Wadi Araba Rift branch developed, revealing the Pan-African Molasse-Sequence (Saramuj Conglomerate, magmatites, volcano-sedimentary deposits) [23] [24] [25] [26], finally followed by the Lower/Middle Cambrian

hydrothermal Cu deposits of Timna and Feidan [27] and continued rift-degassing during the Cambrian and Lower Ordovician; the latter led to the formation of the thick quartz arenite sequence [13] (Um Ishrin F., Disi F.) during environmental acidification. Block faulting encountered in wells (Natural Resources Authority, Jordan (NRA)) occurred during Hercynian Mt. building [10].

During the Triassic subvolcanic sills and dikes that sourced in continental rift-magmatism, intruded along the Dead Sea area into the Cambrian and Permo-Triassic sequences [28]. They correspond to Neo-Tethys rifting, which generated the passive continental margin of the Levant Basin by down-step faulting up to Jurassic/Cretaceous b.

The Jurassic exposes ~450 m thick shallow marine mixed siliciclastics/carbonate rocks deposited under tectonically quiet conditions [29], finally peneplained and overlain with a ~1.5 m thick amalgamated paleosol comprising the Jurassic/Cretaceous transitional zone [30].

The main pulse for the post-Jurassic tectonic activity along the rift system meets the initial opening of the S Atlantic, the subsequent NNE directed motion of the African Plate and its collision with western Eurasia [1] [2] [3] [4]. The Lower Cretaceous Asher volcanism in Palestine [30] [31] [32] [33] [34] as well as the paleosol formation (Berriasian to Hauteriviian) relate to the latter [29].

For understanding of the fast change of lithofacies, sediment thickness, synsedimentary tectonics and faunal diversity on the Jordanian Platform [31] [32] [33] [34], a deformation ellipsoid for the transitional zone of both the Arabian Plate and the Levant Block may explain the sedimentary processing throughout the Cretaceous and post-Cretaceous Dead Sea-Jordan Valley rifting (**Figure 2**, **Figure 3**). It exposes the main shear planes S1, S2 and the general direction of compression and extension; all structural planes are realized up to nowadays:

- Over-regional NW directed shear zone (African Plate motion)
- Post-Cretaceous NNE directed Jordan Valley Rift (S2)
- ENE directed Syrian Arc (Palmyrides)
- Main NW-SE compression, main NE-SW extension
- Cretaceous transtensional/transpressional movements (strike slip-tectonics), mainly occurred along S2
- NW directed “Karak faults”

Thus, the eastern Mediterranean and NE Africa underwent orogenic movements around the JKB [30]-[39].

During the Lower Cretaceous unconfined braid planes expose quartz arenite fining upward cycles (FUC) across the NW dipping Jordanian Platform, northward intercalated with mixed dolomite-siliclastic tidalites interpreted as short initial incursions of the Tethys heralding the Cenomanian main transgression [40].

The Late Cretaceous sediments were deposited in basins and swells of low bottom topography relating to tectonic pulses of the Syrian Arc Fold Belt [29] [36] [38]. With increasing water depth and tectonic activity towards W, thickness increases from a few tens of meters of siliclastics in the E (Kilwa Block) to

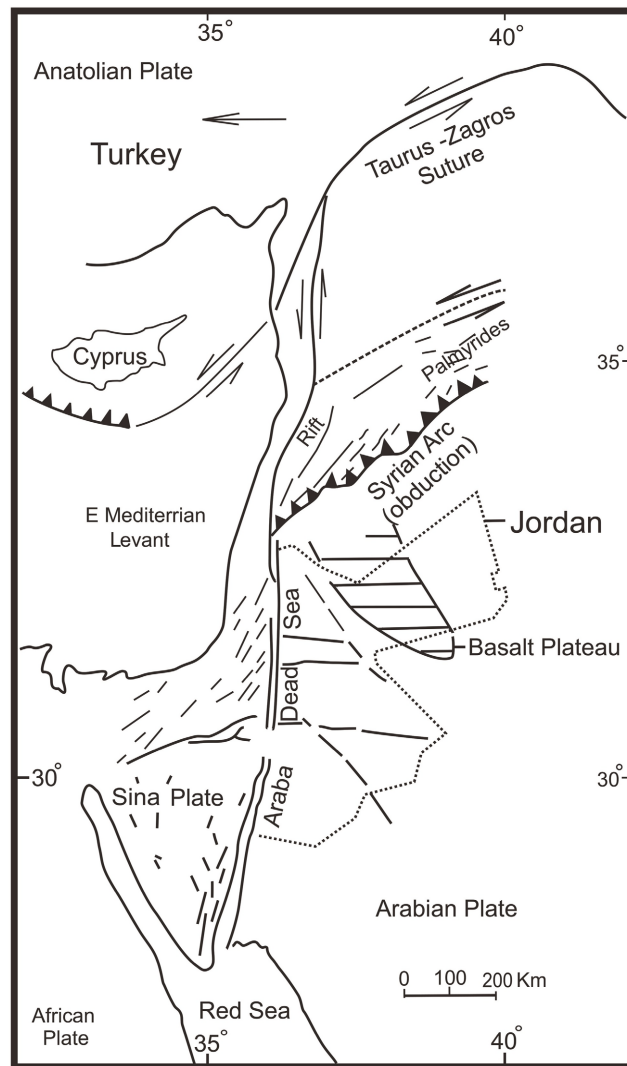


Figure 2. Tectonic setting and major structures in the Near/Middle East, transitional some of the Arabian Plate and the Levant Block [35] [36] [37].

400 - 650 m of mixed carbonate rocks, chert, phosphorite (Central Jordan, Levant). The economically important phosphorite belt extends from N Africa via Levant, Jordan, Syria, and Saudi Arabia to the Persian Gulf documenting upwelling zones along the Gondwana Shelf [31] [32] [33].

2. Cretaceous Sedimentary Processing Affected by Magmatism (LIPs) via Climate Forcing

By the end of the Gondwana Phase [38] at the JKB, the Syrian Arc developed in connection with the initial opening of the S Atlantic and the NNW directed motion of the African Plate [12] [41] [42]. **Figure 2** and **Figure 3** expose the physiogeographic-geologic provinces and tectonic structures of Jordan [35] [36] [37] [38], while [43] provides the Global Stratigraphic table [GSS, 2017] for correlation of numerical-biostratigraphic age with geodynamic/LIP events and some sequence-analytical patterns.

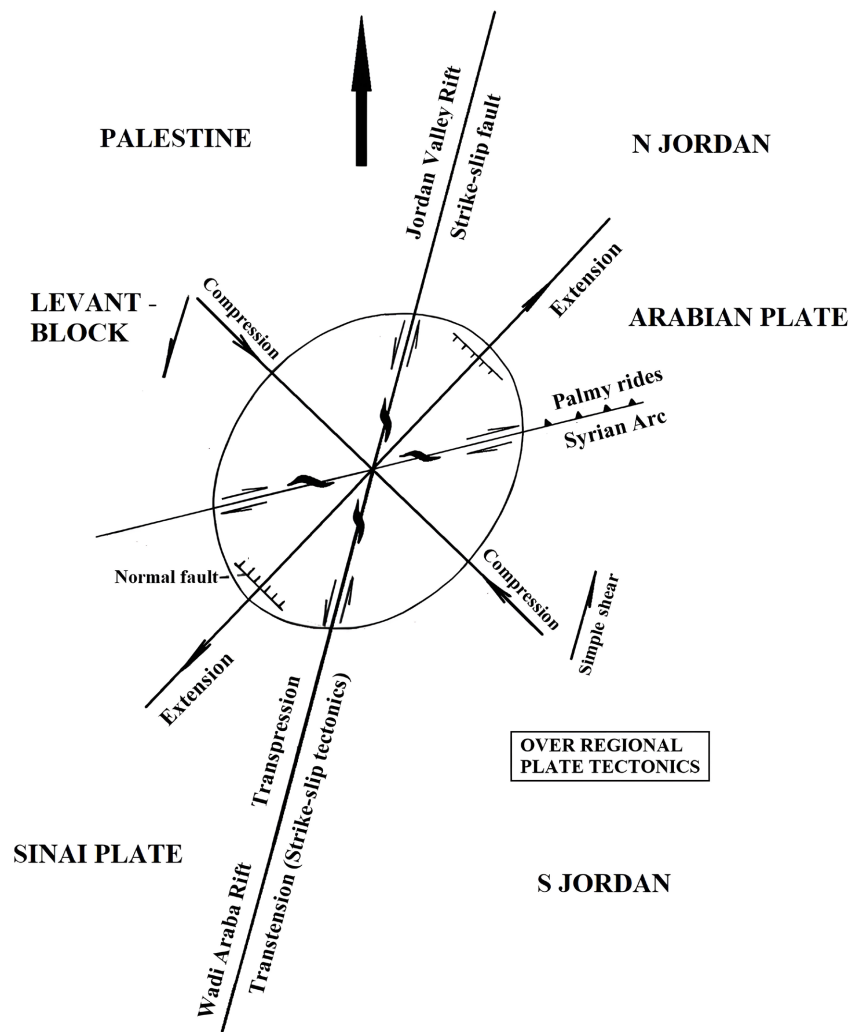


Figure 3. Deformation ellipsoid for the transitional zone Arabian Plate/Levant Block with the sinistral strike slip Wadi Araba-Dead Sea-Jordan Valley Rift. S1, S2 major shear planes, direction of extension and compression, and the over-regional initial shear zone (African Plate motion), striking SW-NE.

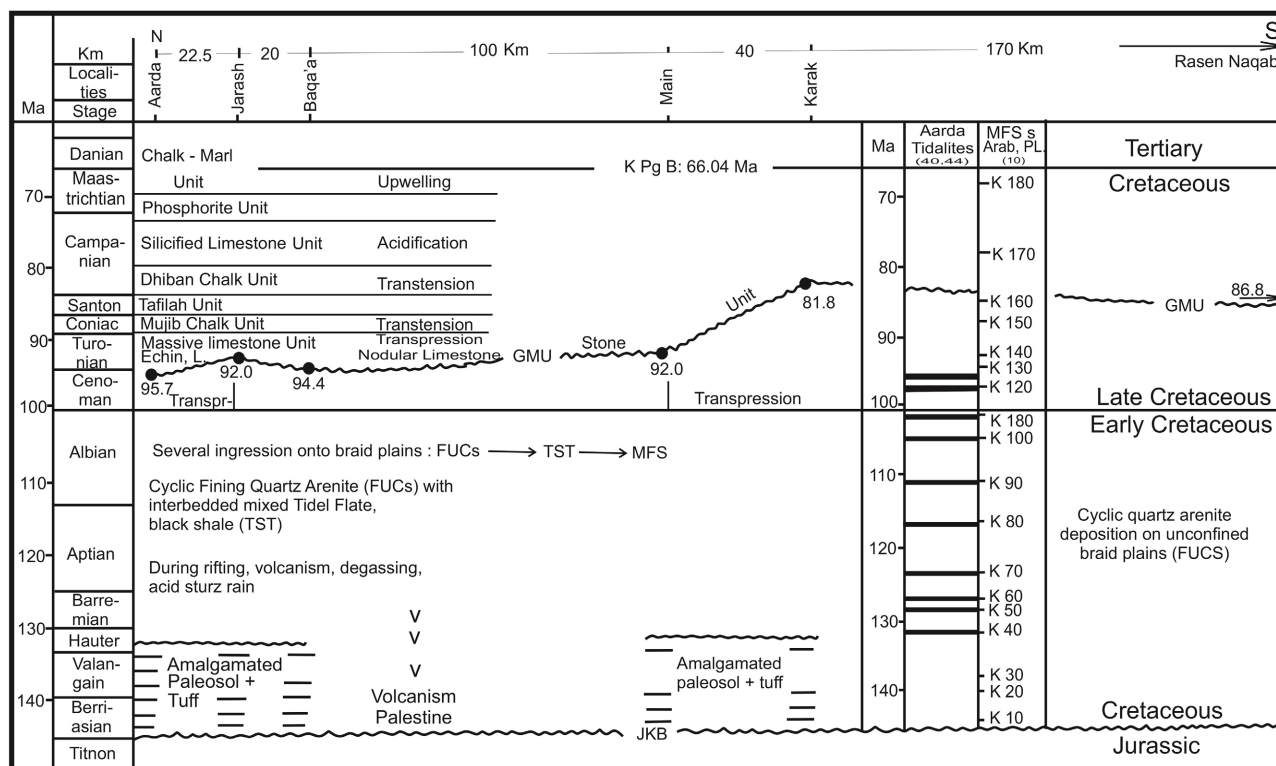
2.1. Early Cretaceous, Jordan (145 - 100.5 Ma, Figures 4-7), Table 1

Berriasian to Hauterivian (145 - 133 Ma):

Across NW Jordan and adjacent areas, the J-K transitional zone exposes a widespread unconformity regionally accompanied by an amalgamated paleosol [30] which comprises a time-span of ~12 Ma. At King Talal Dam, Mahis, N Jordan, it exhibits, in its upper part, a friable milky-white loamy zone consisting of unusual clay-mineralogic assemblage [3] (**Figure 5(A)**, **Figure 5(B)**): illite, chlorite, irregular mixed layer minerals *sudoeite/illite/chlorite/smectite/kaolinite*, kaolinite and natroalunite [30]. This unit may be interpreted as a transformation product of tuff under tropical continental conditions originally sourced in the Tayasir volcanism of mafic-intermediate signature in Palestine (Wadi al Malid, Wadi Fari'a) relating to deep faults along the transitional zone of the Levant Block/Arabian Plate [34] [35] [36] [37] [38].

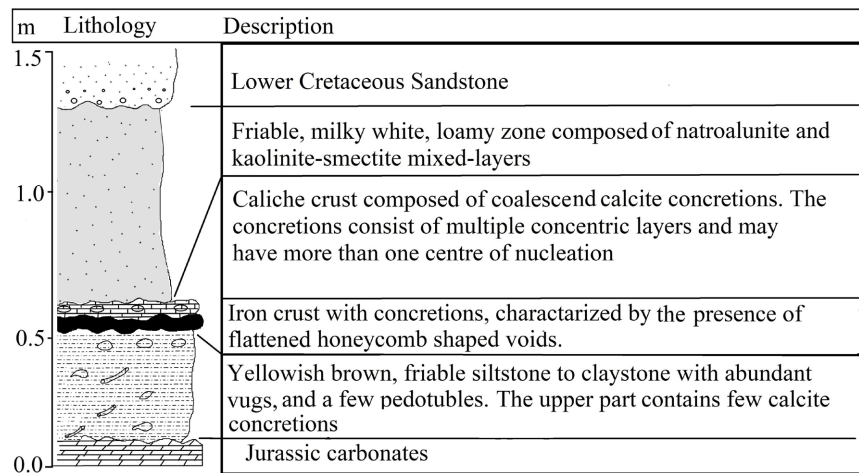
Table 1. Interacting geodynamic events and potential driving forces throughout the Early Cretaceous.

Place/phenomena	Geodynamic	Age Ma	Volume, Velocity mm/yr	Reference
Gondwana related	Paraña/Etendeka LIPs	134	$122 \times 10^3 \text{ km}^3$	[3] [4]
South America	Track change	~134		[2] [3]
MORNs	NW Atlantic	~145 - 130	$1 - 4 \times 10^3 \text{ km}^3$	[5] [6]
Subduction related, High Arctic, Canada	Explosive Island and volcanism (Tuff)	150 - 135		[5] [6]
Okhots-Chukchi volcanic belt	Sills, dike, subvolcanism, andesite, tholeiitic flows	~135 - 100		[5] [6]
Ontong Java Plateau	LIP	119		[3] [46]
Plates	Velocity change	135 - 120	50 - 100	[6] [9]
		120 - 105	45 - 50	
		105 - 96	150 mm/yr	
Earth	Magnetic field	~125	Reversal to normal	[7]
Global	Surface temperature and sea level/dissemination			[7]

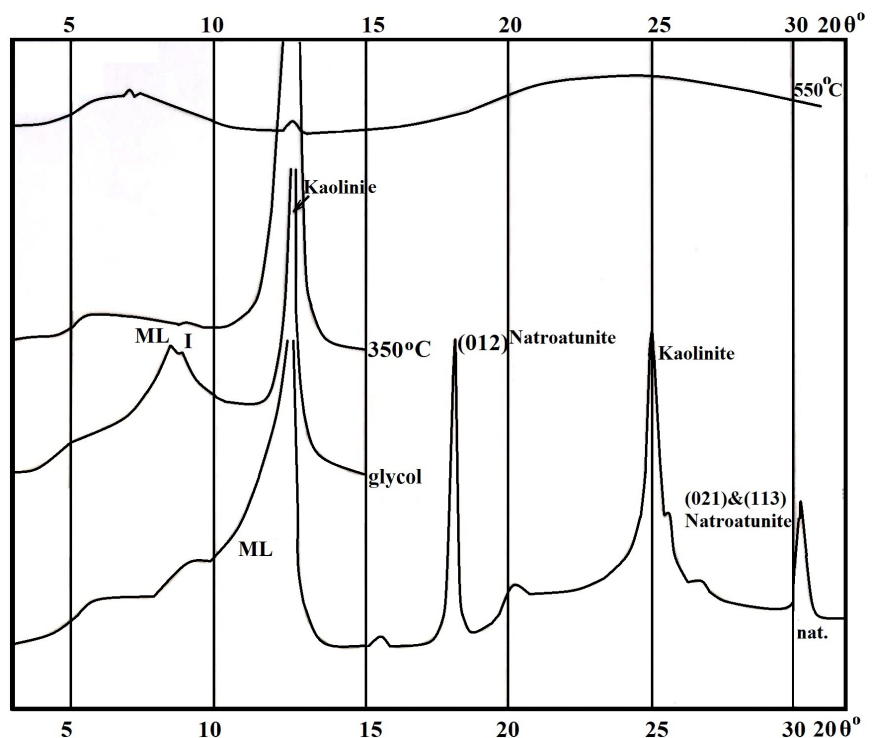
**Figure 4.** Overview of the Cretaceous sedimentology of Jordan. Note facies shifting between the Cenomanian and Campanian during southward transgression of the Tethys verified by glaucony age determination [44].

However, coeval potential sources of global scale may be also concerned:

- Rifting and magmatism in the NW Atlantic, sill volume $1 - 4 \times 10^4 \text{ km}^3$ [5] [6] (~145 - 130 Ma).



(A)



(B)

Figure 5. “Amalgamated” paleosols, King Talal Dam site, Jordan showing tuff-suspicious massive claystone (A) XRD-curves (air-dried, glycolized, 350°C, 550°C (B).

- Subduction related arc volcanism, Canada [5] [6] (~150 - 135 Ma).
- Sills, dikes, and andesitic/basaltic flows at Spitzbergen [5] [6] (~145 - 130 Ma).
- Paraña/Etendeka LIP [4] (sills 122.000 km³, after ~134 Ma).

These geodynamic events meet other paleosol formations in the Near East and the origination of the Inner Hellenic Suture (ophiolite) Greece [41] [42] as well as two sequence boundaries on the Arabian Plate [10] (149.5 Ma - ~136.4 Ma) separated by the “amalgamated” MFS K 40 (~132 Ma) (Figure 6).

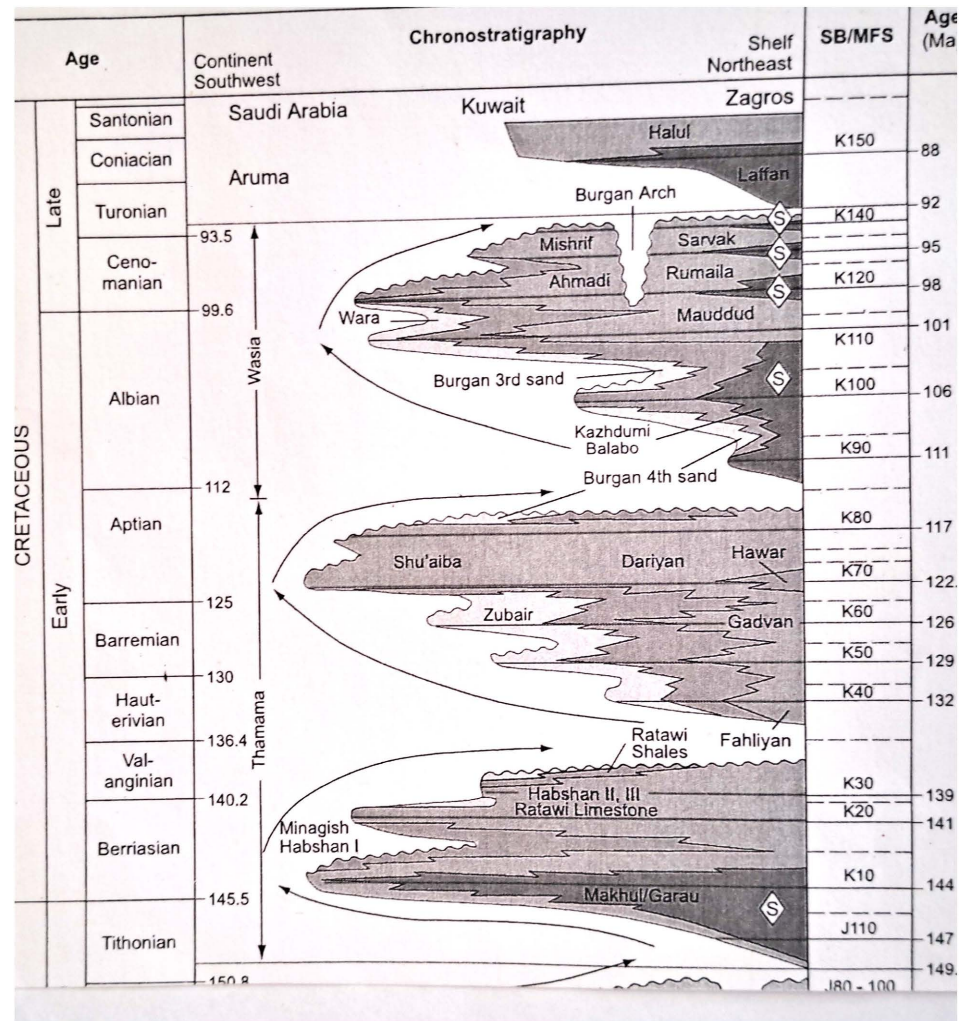


Figure 6. Cretaceous chrono-stratigraphy and MFSs on the Arabian Plate [10].

Hauterivian to Lower Cenomanian, Kurnub Group (133 - 96 Ma)

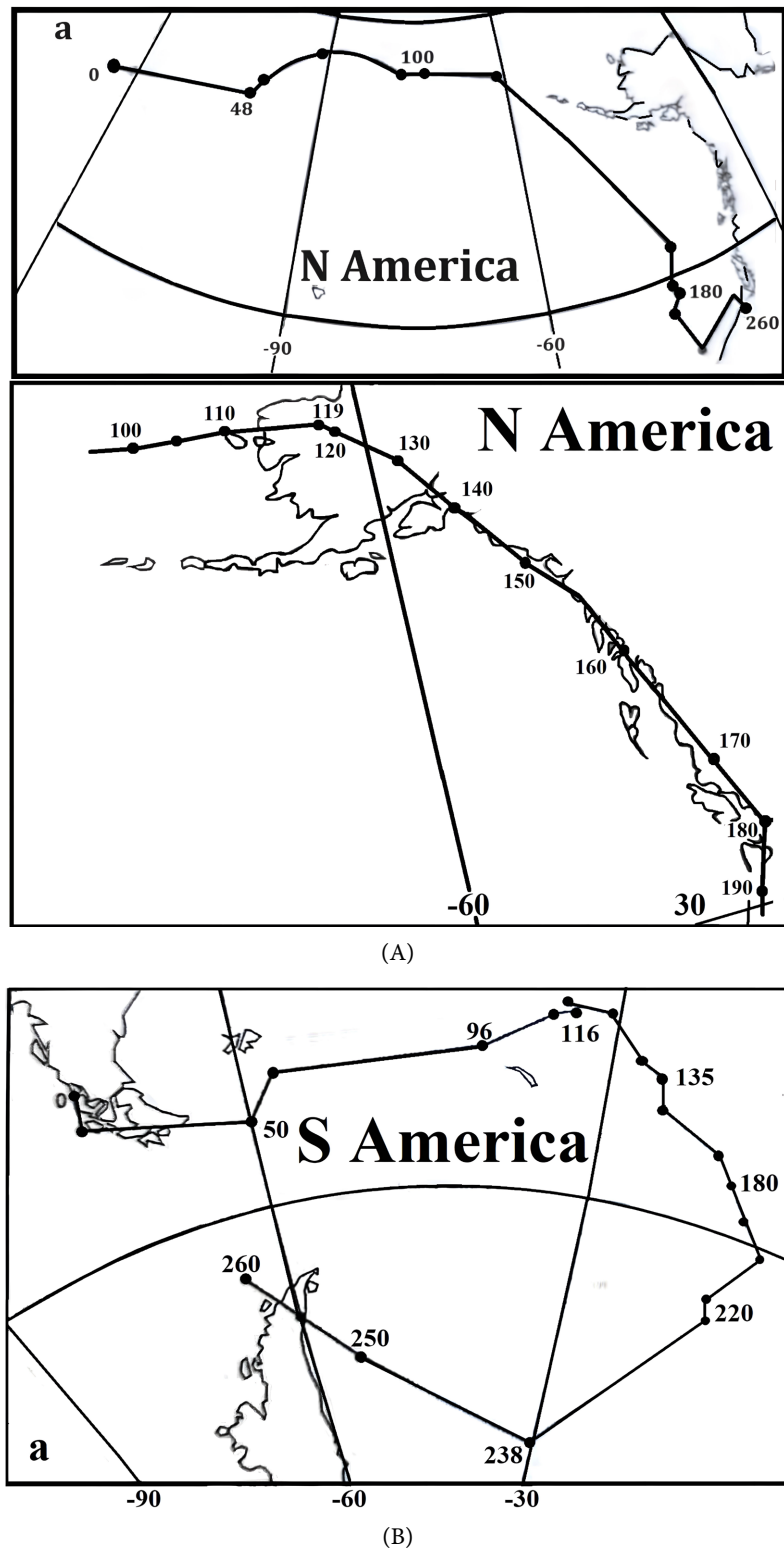
The 220 m thick, predominantly siliclastic suit, is mainly composed of quartz arenite fining up cycles Flash Flood Deposits (FUCs) [40] (Figure 4), however, exhibiting in N Jordan several ingressive trends documented by glaucony-bearing dolomite-siliclastic shale cycles while the SE Platform completely exposes quartz arenite FUCs as river-dominated unconfined braid plain deposits shed from the southerly located hinterland.

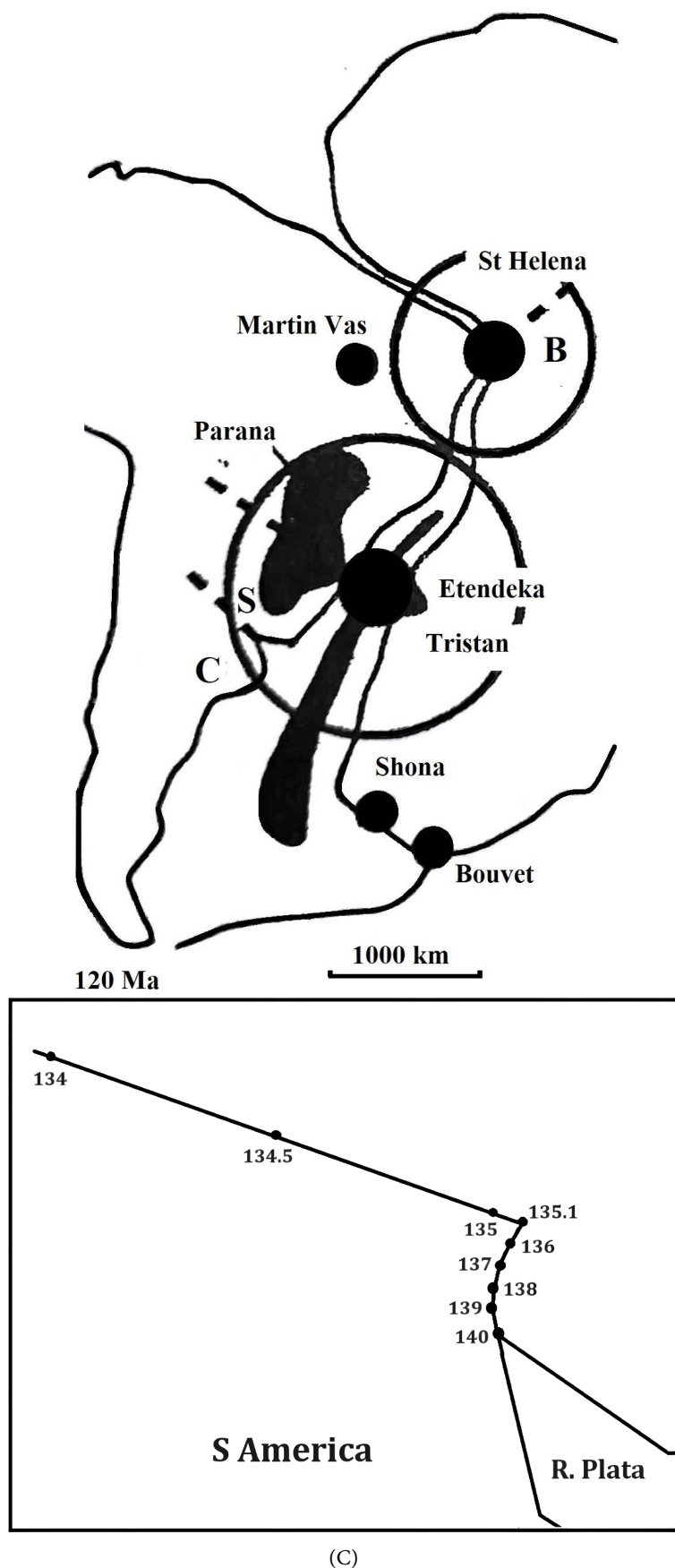
As encountered in several other Phanerozoic quartz arenite sequences on the Jordanian Platform, such FUCs relate to cyclic acid sturz rain events initiated by magmatic degassing and volcanic eruptions during climate forcing [12] [13] [15] [18]. Grey-violet thin pelite/claystone beds are interpreted either as cycle tailings or as tuff/tuffite by an almost complete lack of clay mineralogic XRD-analysis.

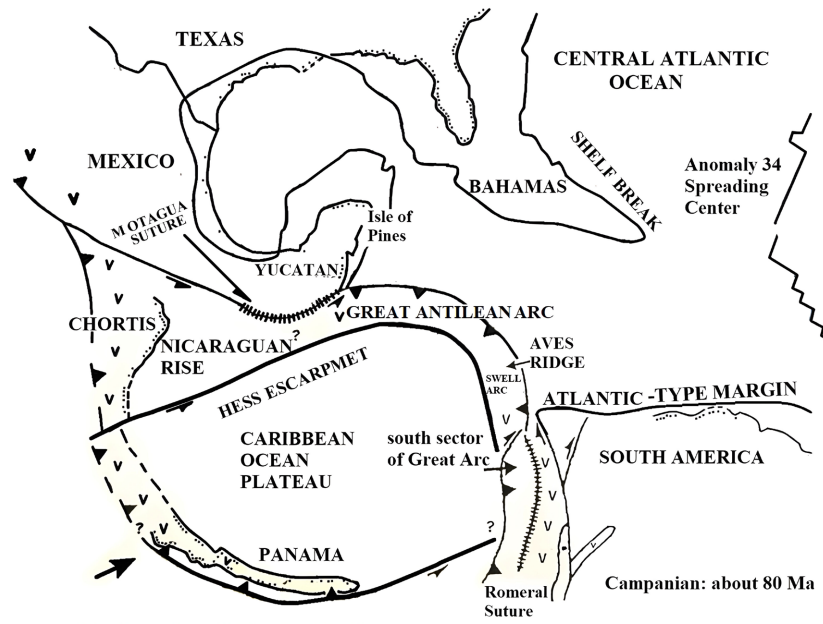
A glauconite marker (GMU) mirrors the southward directed diachronous coastline shifting along 450 km within a time span of ~9 Ma (96 - 87 Ma) up to the Cenomanian Nodular Limestone Member [44] (Figure 4).

Figure 4 and Figure 5 evidence a positive correlation of the short marine in-

cursions on the Jordanian Platform with the MFSSs (K40 - K130) on the Arabian Shelf [10]; accordingly, the quartz arenite FUCs relate to the SBs on the latter. Thereby, the “amalgamated” MFSSs K10 - K30 may be interpreted as affected by geodynamic events (**Table 1**).

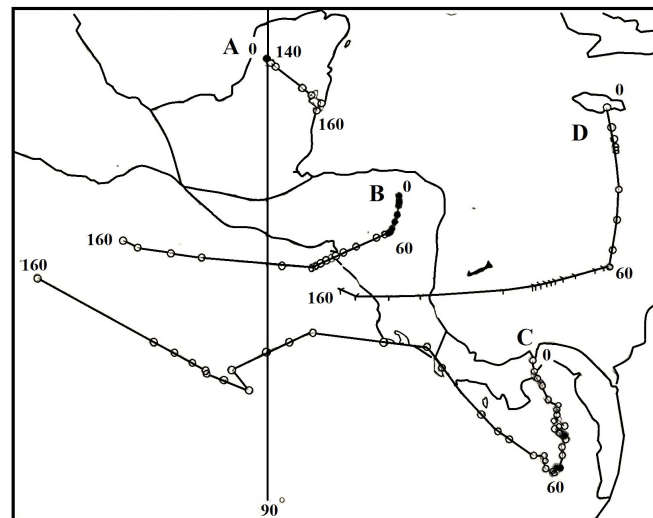




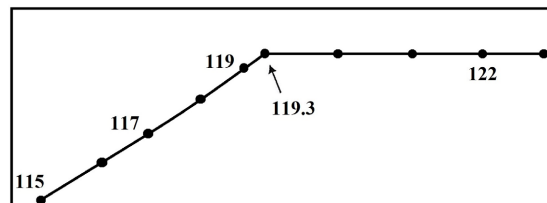


Backtracks relative to Mexico

- A Yucatan 160- 140 Ma SE to NW 140-0 Ma. No movement
 B Nicaragua 160- 61 Ma Mainly W to E 60-0 Ma. S to N
 C Panama 160- 0 Ma Continental movement U- turn 60 Ma
 D Jamaica 160- 61 Ma W to E 60-0 Ma. S to N



(D)



(E)

Figure 7. Track change (direction, plate velocity) of N America (A), S America (B), Parana/Etendeka *et al.* in the S Atlantic (C), Great Antilles Arc, Caribbean (D) and Ontong Java LIP (B).

2.2. Early Cretaceous, Germany [45]

Figure 1(B) shows the setting of the NW German Basin during continuous subsidence that provided a high thickness (~2000 m) for deposition of basinal mudstone, black shale, chalk, marl/tuff and marginal sandstone between the Tethys and the boreal N Atlantic via Carpathian Sea Way [11].

The Berriasian still represents a closed brackish environment with first marine incursions from the NW Atlantic. The Valangian and Hauterivian verify a main transgression over Europe. Boreal fauna dominates during two Tethys incursions during the Late Valangian.

A regression occurred around the Hauterivian/Barramian b. by deposition of ~200 m thick black shale (6% - 8% TOC) as a widespread anoxic event exhibiting an endemic species evolution [45].

During Aptian and Albian, several major transgressions via additional sea ways took place. Deposition of ~200 m clay, black shale intercalated with marly chalk and marl/tuff beds with cosmopolitan faunal elements, dominated NW Europe.

Sea level rise occurred, coinciding with the MFSs on the Arabian Plate [10] during the Valangian base (K30), the Hauterivian (K40), the Barremian base (K50, K60), Aptian (K70, K80), and the Albian (K90, K100, K110) (**Figure 4**).

Faunal diversity (cephalopods, nannoplankton, forams, radiolaria) as well as physico-chemical conditions vary according to Boreal/Mediterranean influence up to cosmopolitan signature in the Albian [45].

Concerning both study areas (Arabian Plate, NW Germany/Central Europe), a couple of geodynamic events meet the depositional time span of the Lower Cretaceous, representing potential driving forces comprising climate change variation (**Table 1**).

2.3. Late Cretaceous, Jordan (100.5 - 66.0 Ma) (Figures 7-9(A), Table 2)

According to the southward directed Tethys transgression, the coastline migrated, as verified by the glaucony marker unit GMU [44], from ~96 Ma in the N (A'arda site) to ~82 Ma in the S (Karak) [44] (**Figure 4**, **Figure 6**). It implies that the lower parts of the Cenomanian are still represented by quartz arenite FUCs in the north with decreasing age of the siliciclastic/carbonate facies boundary to the south [32] [44] [46]-[51].

Middle Cenomanian to Turonian (96 - 82 Ma)

With the Cenomanian transgression (Shallow marine mixed carbonate deposits of the Nodular Limestone M. (NLM)), tectonic activity arose along the later Dead Sea Rift [47] [48], whereas, the lithofacies and thickness rapidly changed southward from 140 m (Baq'a site) to tens of meters on the platform with siliciclastic input [47].

However, the Wadi Mujib section, E Dead Sea exhibits regional uplifting, karstification through ~20 m deep relief with a subtidal/intertidal carbonate li-

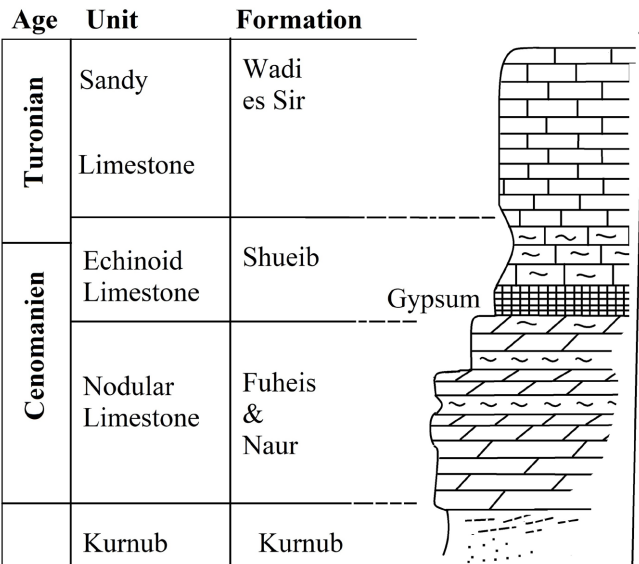
thofacies assemblage, NW drainage, basal fluviatile conglomerate, and massive lacustrine early diagenetic dolomites [47] [48] (Figure 8(A), Figure 8(B)). This verifies an abrupt environmental change (Island horst structure), which extends along the later Dead Sea Rift tailing out to N and S and allows an interpretation by transpressional strike slip tectonics (Figure 3).

Around the Cenomanian/Turonian b. (~94 Ma), further transpressional tectonics is indicated by an unusual 10 - 30 m thick cyclic carbonate, gypsum, green greystone/pelite/marl sequence [49] (Figure 8(A)) along ~100 km N-S extension between Wadi Mujib/Wala and Wadi al Hasa.

The almost fossil-free, green-grey (rarely red) fines are intercalated through six cycles of early diagenetic dolomite and limestone (cross-bedded grainstone, oosparite, ripples, cracks, lamination) containing very rarely benthic forams and ostracods as well as gypsum beds (0.4 - 7.0 m thick); the latter reveal a nodular,

Table 2. Interacting geodynamic events and potential driving forces throughout the Late Cretaceous.

Driving force	Area	Age Ma	Reference
Gondwana related LIPs	- Continental: Madagascar	87	[4]
	- Deccan Traps	66.3 - 65.5	
	- Oceanic Plateaus Agulhas Pl. and Central Kerguele	100	
	- Broken Ridge and Sierra Leone Rise	95	
LIPs: High Arctic, NW Atlantic-related	• MORB rifting transtension.		[5] [6]
	• Subduction related explosive islands arc volcanism in the High Arctic: Okhotsk-Chukchi volcanic belt (OCVB)	105 - 80	
	• High plate velocity of the Kula Plate	105 - 60	
	• Other LIPs:		
	• Great Atlantic Arc	73.1	[3]
	• Amirante Arc Seychelles	67.68	[3]
Chicxulub Impact		66.043	[3] [55] [56] [57] [58]



(A)

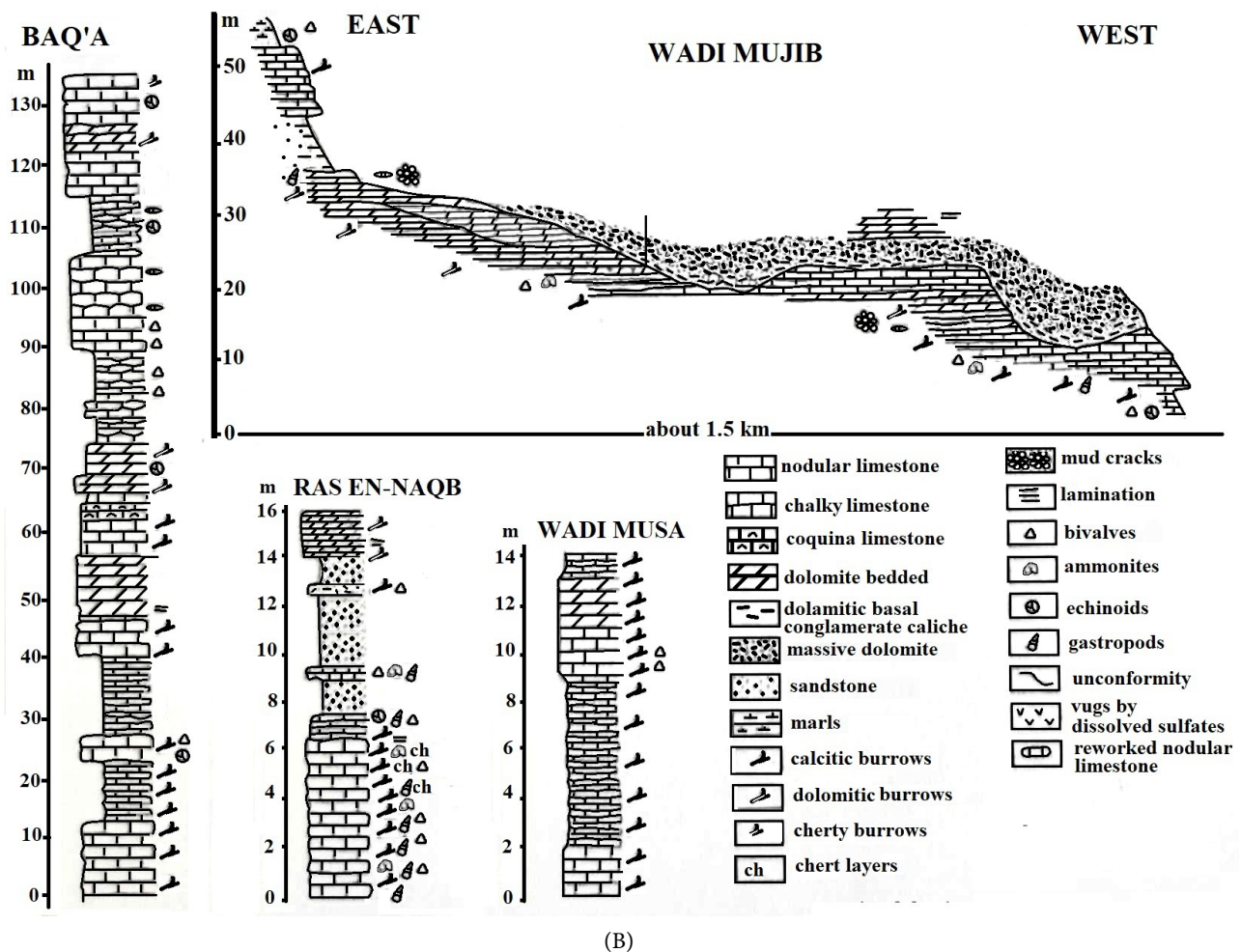


Figure 8. Lithostratigraphy of the Middle/Upper Cenomanian to Turonian (Wadi Mujib, E Dead Sea) under transpressional conditions [47] [48] [49]. (A) General lithostratigraphy. (B) Emersion and karstification of the Lower Cenomanian (E Dead Sea).

laminated or grained texture, and interfingering with normal marine marl/limestone of the typical Shueib F. [49] [50]. Obviously, the deposition occurred in isolated uplifted blocks owning elongated shallow hollows, ponds, lakes under increasing salinity without direct connection to the sea and highly restricted life conditions.

Unfortunately, clay-mineralogic XRD analysis of tuff-suspicious pelite is not available in contrast to our former studies [13] [16] [19], where subduction related explosive island arc volcanism provided glass bearing tuff for transformation to K-bentonite (smectite, montmorillonite) under $\text{pH} > 7$ conditions [19] [20].

First chert nodules in the overlying 85 m thick Massive Limestone F. (Wadi Sir) indicate the beginning of sea-/pore water acidification [50] by decreasing pH.

Relevant magmatic drivers for the time span ~96 - 89 Ma were situated in the High Arctic [15] Okhotsk-Chukchi Volcanic Belt (OCVB, MORB) as well as dike and sill degassing in the Central/Eastern Arctic [6]. For explaining the up-

lifting during this time span along the E Dead Sea area, the deformation ellipsoid (**Figure 3**) provides insight into the initial collision of the African and Anatolian and W European Plate along the Levant/Arabian Plate transitional zone accompanied by environmental/lithofacies consequences around the Cenomanian/Turonian b.: both shear planes S1/S2 represent by their dextral resp. sinistral character the effect of the main NNward directed African Plate motion; thus S2 followed the former Wadi Araba rift zone [19] [22] [23] [26] [35] as well as the later post-Cretaceous Jordan Valley Rift zone [29] [35] [36] [37]. The Syrian Fold Belt (**Figure 2**) followed S1 and NW/SE striking faults, the direction of the main pressure.

Thus, the ellipsoid represents the mechanical forces on the Levant Block/W Arabian Plate, where an over-regional SSW/NNE directed shearing process developed as the driver of the African Plate collision with the W Eurasian Plate during the initial opening of the S Atlantic.

Coniacian, Mujib M. (89 - 86.5 Ma)

Overlying a hard ground/omission plane (Turonian-Coniacian b.), an abrupt change from common shallow marine platform deposits (shelly wackestone, detrital chert, phosphate grains, dolomite) of the Massive Limestone M. to a ~20 m thick detrital chalk sequence took place [50]. The latter interfingers and is tailing out to the S and E with common platform deposits of the Inner Shelf, where several additional hardgrounds indicate varying water depth and tectonic quietness. Silicified coccolith particles and radiolarian relics give hint on primary chalky ooze that early diagenetically-transformed to porcellanite, Tripoli under changing $p\text{CO}_2$, pH and $\text{SiO}_2 \cdot x\text{H}_2\text{O}$ [32].

The abrupt change of lithofacies, increasing water depth and environmental conditions are interpreted by regional transtensional tectonics (pull-apart type) (**Figure 3**), coeval with plate velocity change in the NW Atlantic [5] [6] and the MFS K 150 (88 Ma) on the Arabian Shelf [10]. Coeval temperature fall [7] underlines negative climate forcing caused by aerosols and tuff eruption sourced in the High Arctic [5] (87 Ma) and in the Central/Eastern Arctic [6].

Increasing assimilation/carbonate production by nannoplankton relates to increasing $p\text{CO}_2$ degassing, while chert breccias are of early diagenetic origin during sea water acidification.

Santonian, Tafilah M. (86.5 - 83.5 Ma)

This “Mixed Mineralogical Unit” is built up of densely interbedded oyster/coquina bearing carbonate rocks, phosphatic dolomite, marl, chert, porcellanite and less siliclastics, partially intercalated by hardgrounds (silcretes, calclites). Varying strike slip tectonics caused fast physical-chemical change on a shallow marine platform segment along S2 (**Figure 3**) east of the Dead Sea.

The Santonian base meets the change from normal to reverse magnetization, sea water and temperature rise [7], volcanics, sills and dikes in the Arctic [6], high volcanic/tectonic activity in MORB oceanic basins, subduction zones, island arc volcanism and high plate velocity in the OCVB (**Table 1, Table 2**) [5] and in the Zagros Belt [10].

Some twelve dolomite, chert, and porcellanite/tripoli cycles indicate high silica input caused by cyclic glass bearing tuff eruptions. Their transformation to colloidal silica/opal C-T during sea water acidification and CO₂ degassing led subsequently to the formation of K-bentonite by halmyrolysis (pH > 7).

Lower Campanian, Dhiban Chalk M. (83.5 - 80 Ma) [32] [50]

As déjà-vu event, the ~70 m thick chalk sequence overlies regionally significant hardgrounds (Santonian/Campanian b.) covered with oysters, corals, detrital chert, phosphatic clasts like that at the Coniacian/Santonian b. It wedges out towards S and E and represents, in a restricted area, a basin filled up with detrital and soft white nannoplankton chalk originated by syndimentary trans-tensional strike slip tectonics (**Figure 3**). Ammonites, reworked oysters, and planktonic forams indicate higher water depths in contrast to the common platform.

Increasing pCO₂ (positive climate forcing) led to growing assimilation intensity during coeval driving forces like:

- Rising temperature and sea level under reverse magnetization [7], an effect of LIP magmatism and plate motion.
- Volcanics, sills, and dikes in the High Arctic [6].
- Maximum subduction and explosive tuff generation ~82 Ma [5].
- MORB oceanic basins [5].
- Maximum plate velocity of the Kula Plate, Arctic [5].

Middle to Upper Campanian, Main Chert M. (80 - 72 Ma) [32]

Some 20 cycles of carbonate rocks (limestone, dolomite) and chert (breccia) build up the ~20 - 50 m thick sequence in Central Jordan bearing bivalves, planktonic/benthic forams and phosphate-coated intraclasts.

Fauna and sedimentary structures (algal cross lamination, graded bedding) indicate shallow marine platform environments.

The cycles are due to pH variation of sea/pore water acidification caused by magmatic degassing under normal magnetization [7]:

- Arctic areas: Alpha Ridge, Kap Washington, Sverdrun [5].
- Rifting in the N Atlantic, falling temperature and sea level [7], and higher plate velocity under transtension [5].
- LIP activity through the Caribbean Arc/Antilles [3] (73.1 Ma).

Lower to Middle Maastrichtian, Phosphorite M. (72 - 69 Ma)

Some ten limestone-chert-phosphorite cycles build up the ~50 m thick sequence in Central Jordan, which, however, miss the Upper Maastrichtian Muwaqqar M. [32] [52], the latter plays an important economic role in SE Jordan.

Faunal elements (bivalves, gastropods, cephalopods, planktic/benthic forams, radiolarians, spiculites) indicate shallow to deep subtidal environments of low TOC and frequent variation of seawater acidification under the influence of continuous magmatic degassing like:

- LIP activity in the Caribbean Arc, Antilles [3] (73.1 Ma)
- Subduction related volcanism in the Bristol-Anadyr Zone (BA) [5]

- Break-up and spreading in the Labrador Sea [5]
- Continuation of magmatic activity in the Arctic region [5]
- Beginning uplift of Mantle Plume in the NW Atlantic [5]
- Falling temperature and sea level under a change from normal to reverse magnetization [7]

Upper Maastrichtian to Danian, Chalk-Marl M. (69 - 61.6 Ma)

The Phosphorite M. is overlain with a broad lithofacies spectrum of regionally varying chalk, marl, and marly and massive limestone [52], ranging in thickness from ~20 m (SE Jordan) to ~450 m (in Al Jafr Basin). Basins of thick chalk-marl deposits strike NW-SE and are intercalated with bituminous shale (*i.e.* Yarmouk area), (Figure 3): deformation ellipsoid).

In the latter area (NW Jordan), the KPgB is localized in the missing Nannoplankton zones *Naphrolithus frequens* and *Markalius inversus* zone (NF1) [53].

As driving forces through the KPgB-transitional zone are relevant:

Amirante Arc, Seychelles [3] [54] [55] (67.68 Ma)

Deccan Trap LIP [55] [56] [57] (66.3 - 65.6 Ma, during Chron 29 R)

Chicxulub Impact [3] [55] [56] [57] [58] (66.043 Ma)

Variation of magnetization, falling sea level and temperature [8] [10]

Decreasing velocity of plate motion (Kula Plate) and subduction related volcanism, beginning Mantle plume activity (Greenland) [5].

The data evidence a complex interplay of drivers that caused several pulses prior to major mass extinction (66.043 Ma), telling: the latter represents an effect of cumulative character.

2.4. Late Cretaceous, NW Germany (100.5 - 66.043 Ma) [45] [59] (Figure 9(B))

Abundance of surface outcrops and wells provide excellent conditions for profound lithofacies, tecto- and tuff event analyses of the fossil-rich NW German Late Cretaceous deposits.

Basically, three main structural units namely; Subhercynian, Rhenian, and the Hercynian Zone are regionally distinguished, influenced by salt tectonics and built up by the following lithofacies group, each exposing marginal and basinal environments [59]:

- Bedded Limestone (Plänerkalk), Cenomanian to Lower Coniacian
- Emscher Limestone, Lower Coniacian to Lower Campanian
- Marly Limestone, Lower to Upper Campanian
- Spiculitic Limestone, Campanian
- Calcarenite, Maastrichtian
- Regionally intercalated: black shale, tuff beds, pelite
- In the Subhercynian Zone (N Harz-Foreland) tectonic inversion converted a former graben structure into the stable Lower Saxony tectogene through the Early Coniacian to Campanian. Further inversion took place in latest Maastrichtian to Early Tertiary. The most extended tidal dissemination occurred during Campanian

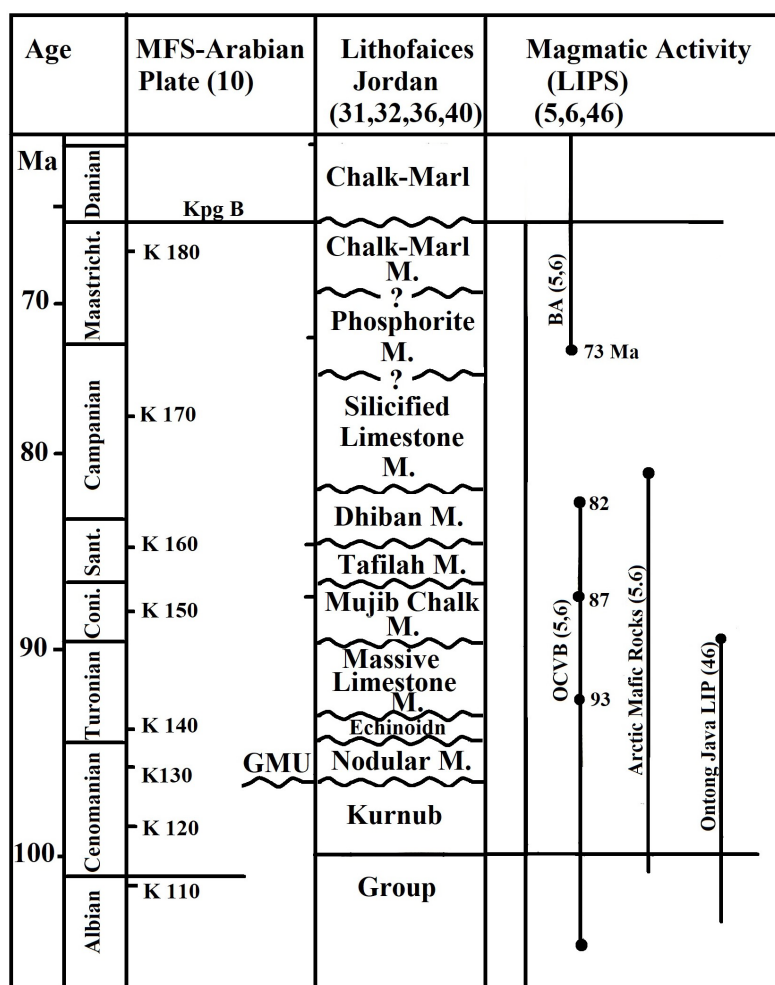
Figure 9 represents eustatic faunal and tectonic events in NW Germany during the Late Cretaceous in connection with lithofacies distribution: The Cenomanian exposes four transgressive phases, a late tectonic event, several additional transgressions through the Cenomanian/Turonian transitional zone, red colored limestone (Rotpläner), a worldwide positive $\delta^{13}\text{C}$ -excursion around ~94 Ma [59] [60] and many intercalated verified tuff beds.

From Turonian to Santonian several transgressions occurred, intermitted by a high number of tectonic events and tuff/tuffite beds [61].

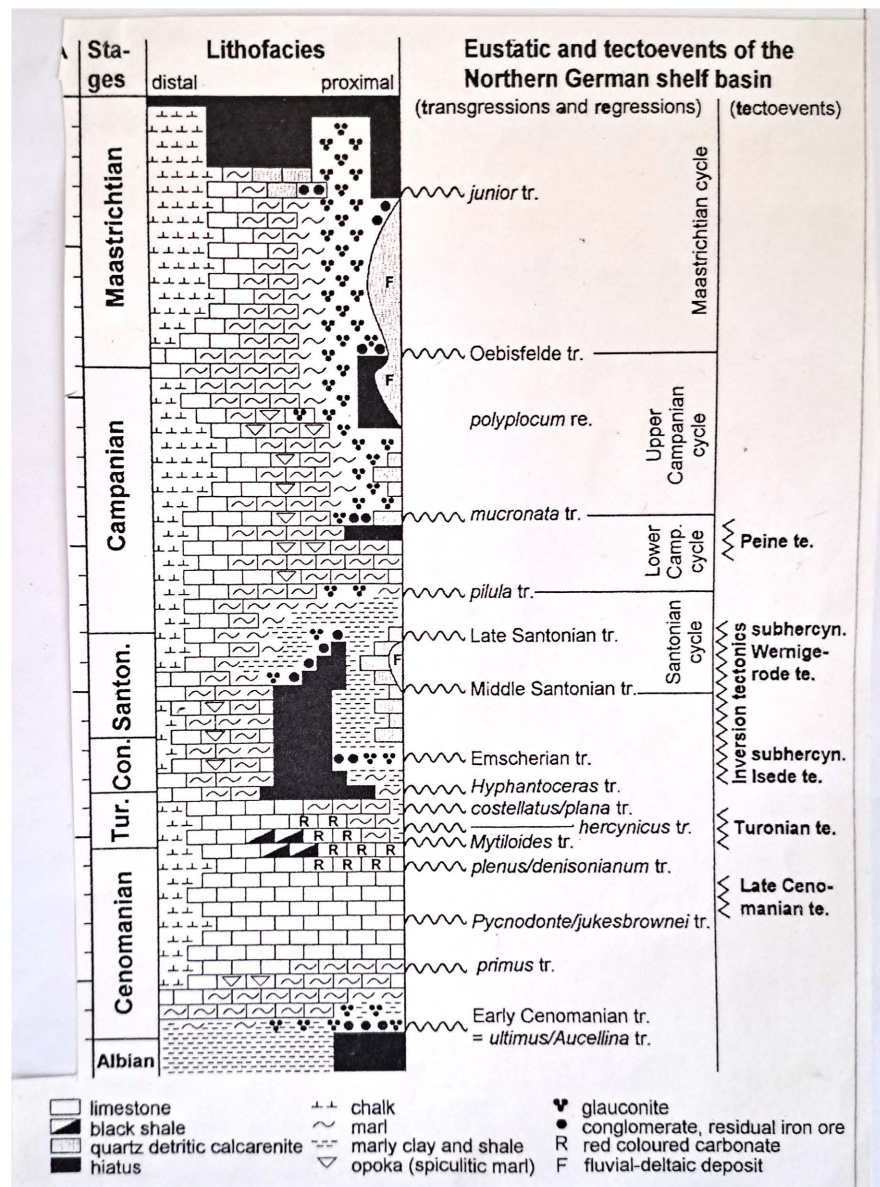
Through the Campanian to Maastrichtian, glauconitic marlstone indicates decreasing Eh. Obviously, some transgressions in NW Germany are coeval with the MFSs (K110 - K180) on the Arabian Plate [10] (**Figure 6**).

Marginal fluviatile-estuarine quartz arenite, deposited on confined braid plains, give hint on environmental acidification sourced in the LIPs and the Chicxulub event [62]. The KPgB has not been verified in NW Germany until now.

Thus, the Upper Maastrichtian meets LIP activity in the American Arc [6] [7], Deccan Traps (66.3 - 66.5 Ma) and the Chicxulub impact (66.043 Ma) being possible contributors for tuff and glass-derived K-bentonite/montmorillonite [61].



(A)



(B)

Figure 9. Lithostratigraphy of the Late Cretaceous on the Jordanian Platform (A) and in NW Germany (B): the latter displays lithofacies, eustatic, and tecto-events [45] relating to major volcanic events [5] [6] [46] and the MFSs on the Arabian Shelf [10].

So, the Cretaceous sedimentary column in NW Germany provides an event-stratigraphy caused by volcanism and tectonics that directed the faunal assemblage [45] [59].

Short note to the KPgB (Figure 10):

While globally, temperature and sea level declined through the Lower/Middle Maastrichtian [7], several T-Pulses occurred by approaching the KPgB (~68 - 66 Ma). The LIPs of the Amirante Arc relate to this time span [3].

However, $\delta^{18}\text{O}$, ^{13}C and clump isotope records through a hiatus-free section across the KPgB and Seymour Island, Antarctica encounter several warming

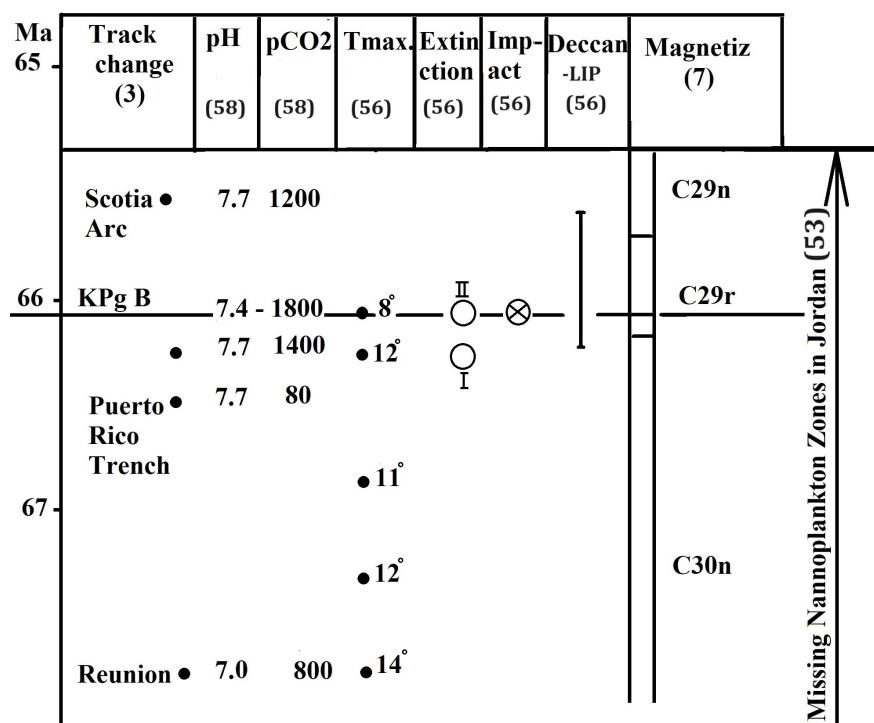


Figure 10. Significant physico-chemical parameters (pH, pCO₂, T), track change of plates, Chicxulub impact, LIP activity, magnetization, and two extinctions!

phases [56]: the first three through 67.8 - 66.9 Ma, a main pulse at 66.24 Ma ($7.8^{\circ}\text{C} \pm 3.3^{\circ}\text{C}$) coeval with Deccan volcanism onset and a smaller one ($1.1^{\circ}\text{C} \pm 2.7^{\circ}\text{C}$) coinciding with the Deccan Trap (until 65.55 Ma) covering Chrom 29R.

Thereby, nine of ten benthic species (mollusks) and one single ammonite sp. were concerned by the first main warming (Deccan V.) of 7.8°C increase, and six of fourteen benthic sp. and all ammonite sp. were extinguished by the impact at 1.1°C increase. So, volcanic onset caused a fast warming up [56]. Indirect effects like ocean water acidification, acid rain and trace metal toxicity would play an additional role.

Global analyses of $\delta^{11}\text{B}$ in forams reconfirm the KPgB age by a significant pH drop (8.4 - 7.5), species diversity decline (60% to 20%) and rise of pCO₂ (800 to 1800 atm) [58]. The complex interdependence of cause and effect represents the KPgB as a cumulative transitional zone and not a single event. Missing of the Upper Maastrichtian to lower-most Danian, nannoplankton zones in Jordan underline this cumulative character [53]. It concerns also the Lower and Middle Campanian, where magmatic degassing caused acidification and the missing of nannoplankton in Jordan and spiculitic marlstone in NW Germany, indicating a higher availability of silica [45].

3. Volcanism-Related Physico-Chemical Implications in the Course of Lithofacies Formation

“Hidden” Tuff Tuffite (Figure 11, Figure 12):

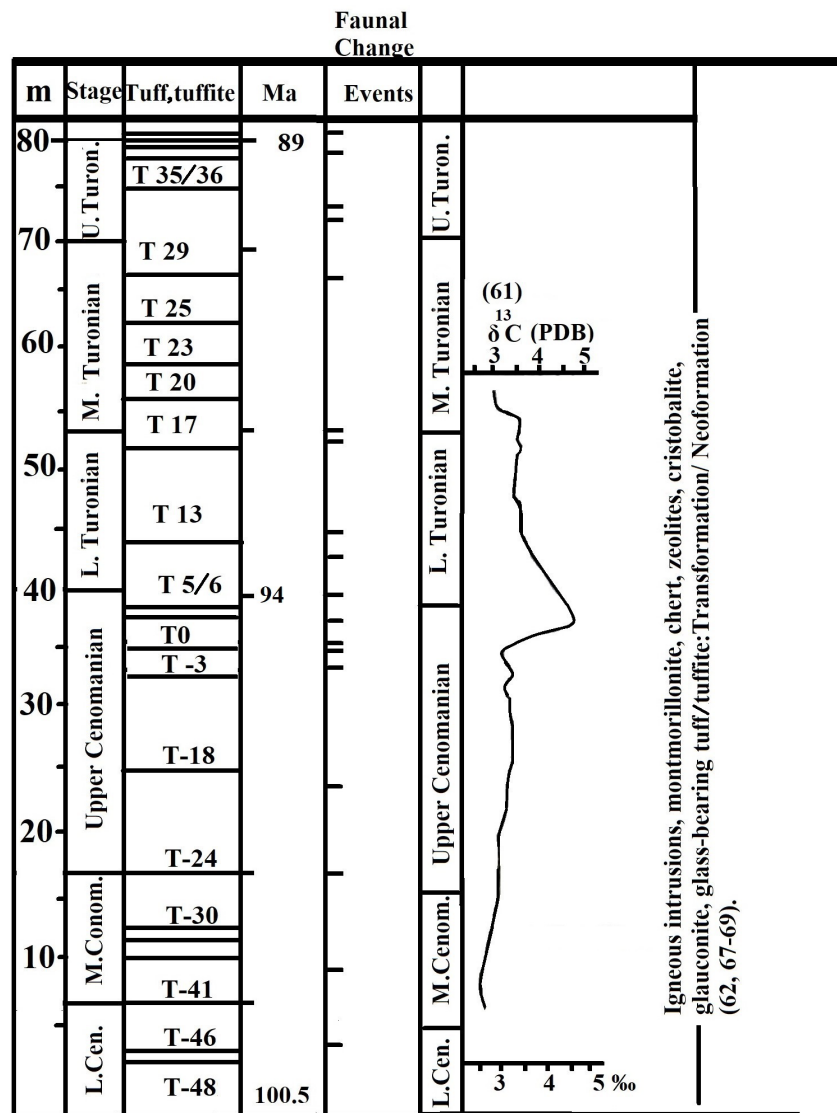


Figure 11. Late Cretaceous tuff/tuffite/tectonic/faunal events through the Hoppenstedt Quarry, North Harz foreland, NW Germany [45] and the $\delta^{13}\text{C}$ curve showing the maximum of the global anoxic event around the Cenomanian/Turonian b.

Throughout the Phanerozoic, sedimentary series, thin beds of pelite (claystone, shale, marl, porcellanite, black shale, tuff, tuffite) have been too rarely analyzed by XRD. As frequently experienced, a broad color band (white, grey, green, black, violet) gives some first genetic hints (*i.e.* [14] [16] [19] [20]).

Best known clay minerals are *i.e.* kaolinite ($\text{pH} < 7$) and montmorillonite/smectite ($\text{pH} > 7$) in various sedimentary environments (*i.e.* [63] [64]) analyzed by their basis reflexes 001, 002, 003, 004 (air-dried, glycolized, heated 350°C , 550°C) and by the 060 reflex for dioctaedric/trioctaedric differentiation.

Of favorite interest during our recent studies appears K-montmorillonite (K-bentonite) as an in-situ transformation/neoformation [63] of glass-bearing tuff relating to subduction-directed explosive island arc volcanism and deposited in marine environments *i.e.* [16] [19].



Figure 12. Photograph from Hoppenstedt Quarry, N Harz coincides foreland, NW Germany. Upper–Lower Cenomanian Turonian transitional zone: marlstone/limestone sequence intercalated with thin dark-brown tuffite layers. $\delta^{34}\text{S}_{\text{max}}$ just below the boundary with T₀-T5/6 [45] (Figure 11). The complete sequence underwent intraformational raft tectonics (Hoppenstedt quarry, Subherzynian Basin, N Germany, SSW-flank of the Fallstein Salt Pillow-structure). The red-colored sediments coincide with increased volcanism (T₀-T36) and are sourced in continental areas by cyclonic dust storms during atmospheric hazards.

Across the Near East marl/tuff beds, volcano-clastics and glauconite (Fe^{2+} , Fe^{3+}) are encountered through the Early Cretaceous [30] [34] [35] [36] [40]. In NW Germany, the Cretaceous is completely concerned by various contents of montmorillonite and more than 20 marl/tuff beds merely through the Cenomanian and Turonian coinciding with tectonic events, faunal change and global magmatism (Table 1, Table 2) [45] [61] [65] [66] [67] [68], so permitting an Event-Stratigraphy.

The Cenomanian-Turonian b. (94 - 95 Ma) exhibits an Oceanic Anoxic Event verified by a $\delta^{34}\text{S}$ excursion [60] (Figure 11) indicating increased temperature, decreasing photosynthesis (pCO_2) and subsequent black shale formation during intensified magmatism (Table 2).

On the Jordanian Platform, tuff/tuffite beds have not been really verified by intercalating the Late Cretaceous carbonate-pelite-chert-phosphorite cycles, plausible by erosion in the shallow water environments, without conservation traps.

However, the grey-green, fossil-free pelite deposits (dolomite-gypsum-pelite cycles) deposited in lakes/lagunes at the near Cenomanian/Turonian b. [49] seem tuff/tuffite-suspicious, in a restricted inter/supratidal environment caused by strike slip tectonics (Figure 3), unfortunately without any available XRD data (Figure 13).

According to [9], dominance of tuff production causes a negative climate forcing in connection with volcanic events (Table 1, Table 2):

- OCVB with maxima at 93, 87, and 82 Ma
- BA from 75 to 60 Ma

While positive climate forcing relates to the dominance of Green House Gases released at:

- High Arctic (100 - 60 Ma)
- Deccan Traps (66.3 - 65.5 Ma)
- Ontong Java LIP (100 - 83.5 Ma)
- Great Antilles Arc (**Figure 9(D)**)

Pyroclastics: Transformation and Mineral Neoformation (**Figure 11, Figure 12, Figure 14(A)**)

Since, by far, subduction related explosive arc volcanism generates pyroclastic tuff/ash of intermediate (andesitic) composition deposited globally in the oceans, it provides abundant silica, Al and other elements for in situ transformation and mineral neoformation during halmyrolysis [63] [69].

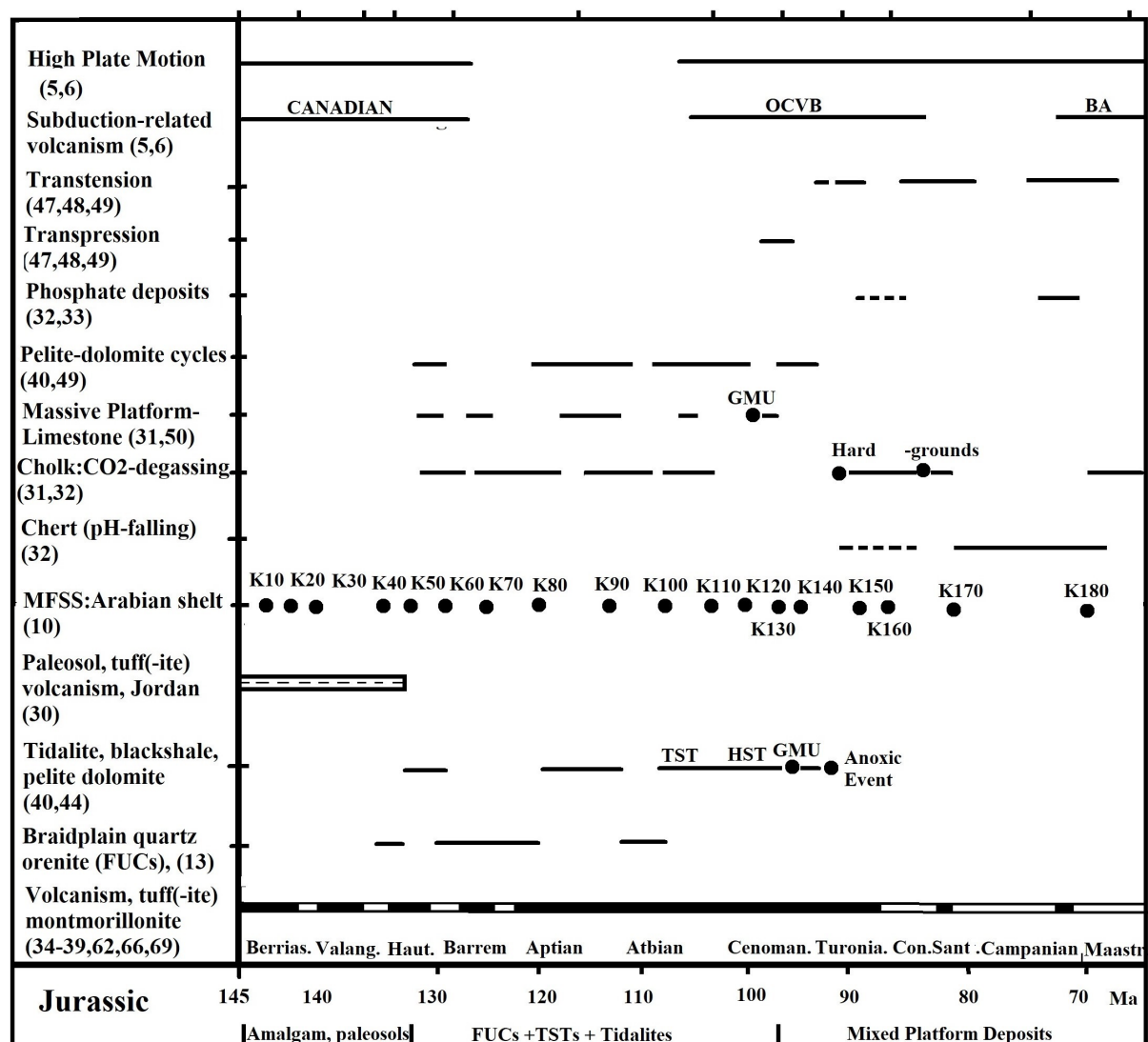
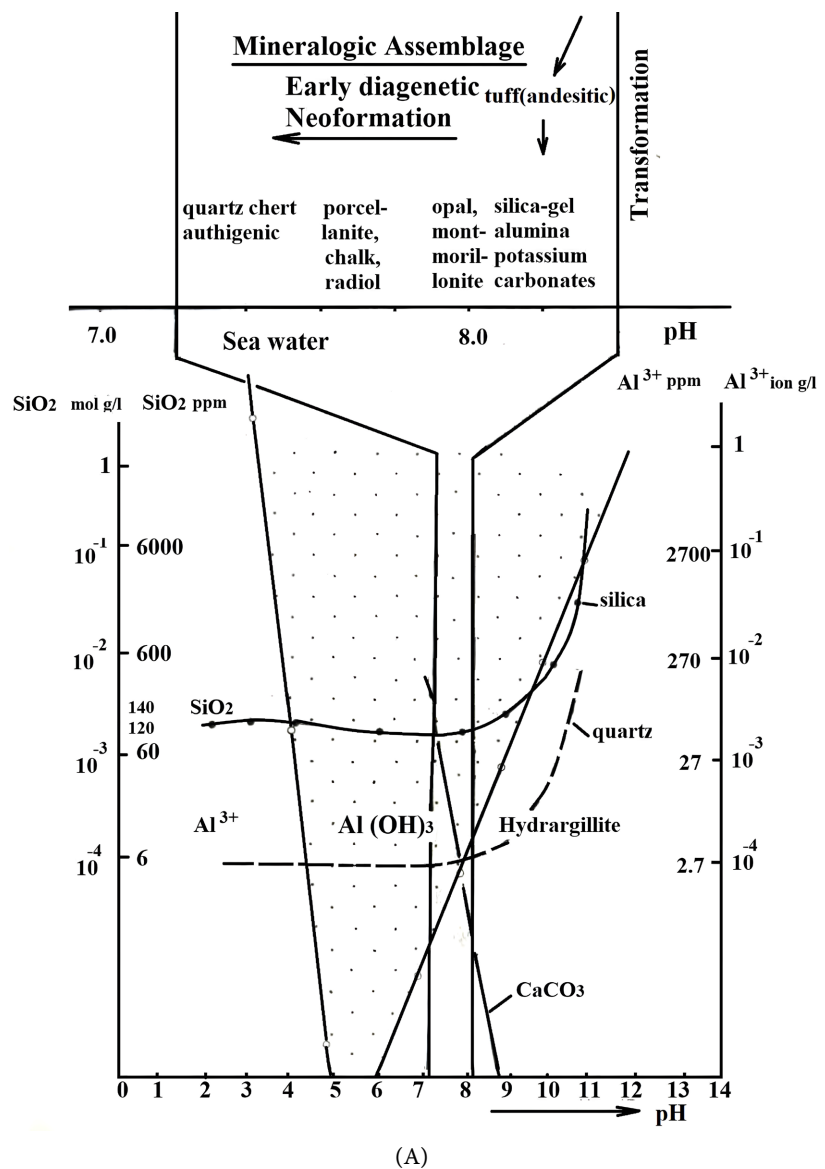


Figure 13. Driving forces and effects on lithofacies and sedimentary processing throughout the Cretaceous.

Thereby, both SiO_2 and Al_2O_3 as well as others (Fe^{2+} , Fe^{3+} , Mg^{2+}) sourced in pyroclastics, are important contributors to silica mineralization and clay mineral neoformation under increasing acidification (pH 7.4 - 8.2) [9]. Further, solution co-travellers like Al^{3+} and Mg^{2+} decrease the solubility of silica between pH 5 - 10.5 [63] so giving rise for rapid facies change as encountered in the silica/chert-porcellanite-carbonate (limestone, dolomite, chalk)-pelite-phosphorite sequence on the Jordanian Platform [63] [64] [69] [70].

However, the in situ neoformation of K-montmorillonite (comp. [19] [20]), based on pyroclastic tuff, has become generally underestimated with regard to the frequency of geodynamic activity through the Phanerozoic [62]. Thus, we expect a higher importance of transformation processing in marine environment for the neoformation of glauconite (Fe^{2+} , Fe^{3+}), illite, chlorite, mixed layer minerals as well as for chert, porcellanite, authigenic quartz, zeolites, and for skeletal opal (diatoms, radiolarian, silicoflagellata, and siliceous sponges).



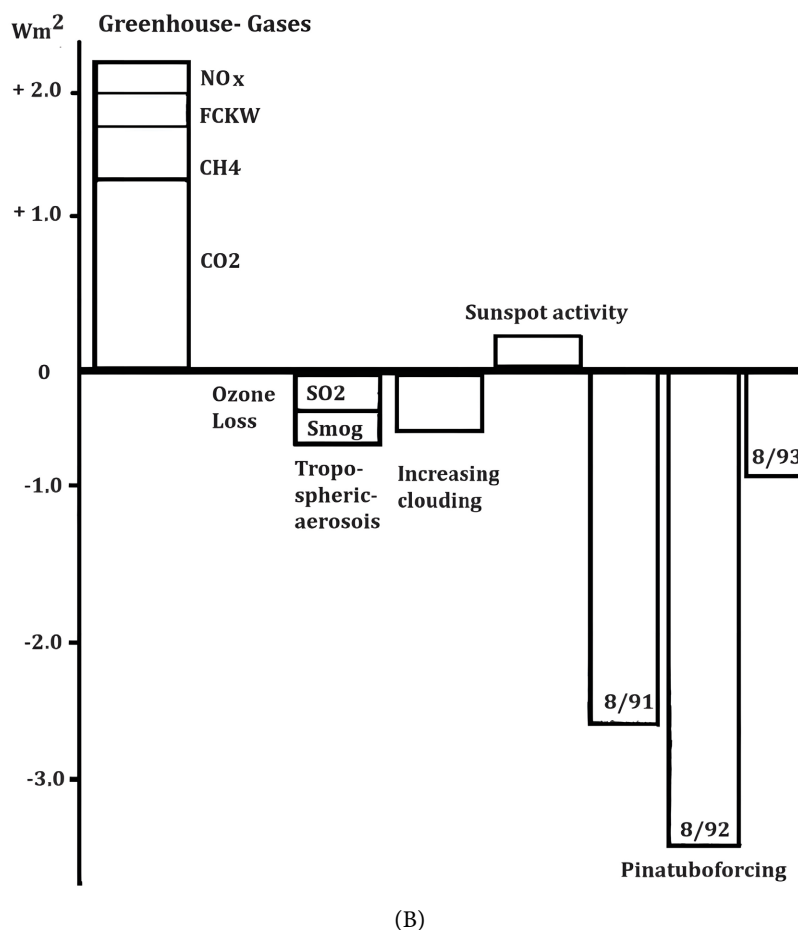


Figure 14. Physico-chemical parameters direct lithofacies formation. (A) Stability fields of silica and alumina depending on pH. The scope pH 7.2 - 8.4 represents environments of montmorillonite, carbonates, silica, chert, quartz, and skeletal opal neoformation [63] [69]. (B) The ratio greenhouse gasses/aerosols, tuff eruptions, clouding direct positive/negative climate forcing (pH, Eh, pCO₂, photosynthesis) [9].

Photosynthesis: Chalk and Black Shale Facies (Figure 15(A))

Chalk deposits dominate the Coniacian, Lower Campanian and the Upper Maastrichtian in Jordan [31] [32], while in NW Germany the Aptian, Albian and the distal (pelagic) environments of Late Cretaceous are concerned [45] [59].

Chalk sediments mainly composed of nannoplankton (Coocophorida) and plankton (forams) occur worldwide via surface production by photosynthesis: $H_2O + CO_2 \rightarrow HCOH + O_2$ [70] [71] [72] [73]; the capacity depends on pCO₂ [73], most plants reach ~55 $\mu mol/m^2 \cdot sec.$ as maximum, and end at ~1100 ppm CO₂ under normal conditions. As calcifier Coocoliths (2 - 20 μm^0) may produce one individual within one hour [71] [72] as providing high sedimentation rates through a short time span.

However, rapid fall of solar radiation caused by aerosols and tuff ash clouding ("Oceanic Winter" = negative climate forcing, Figure 14(B)) leads to subsequent decay of phytoplankton during growing volcanic-pCO₂ and -TOC, but decreasing pH, Eh and the development of black shale facies [69] [70].

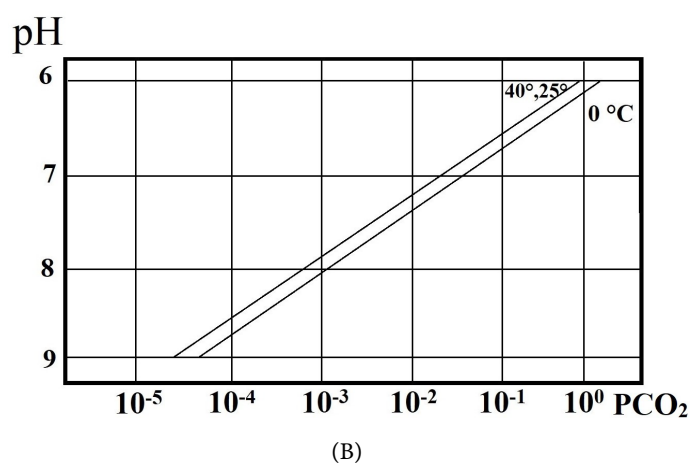
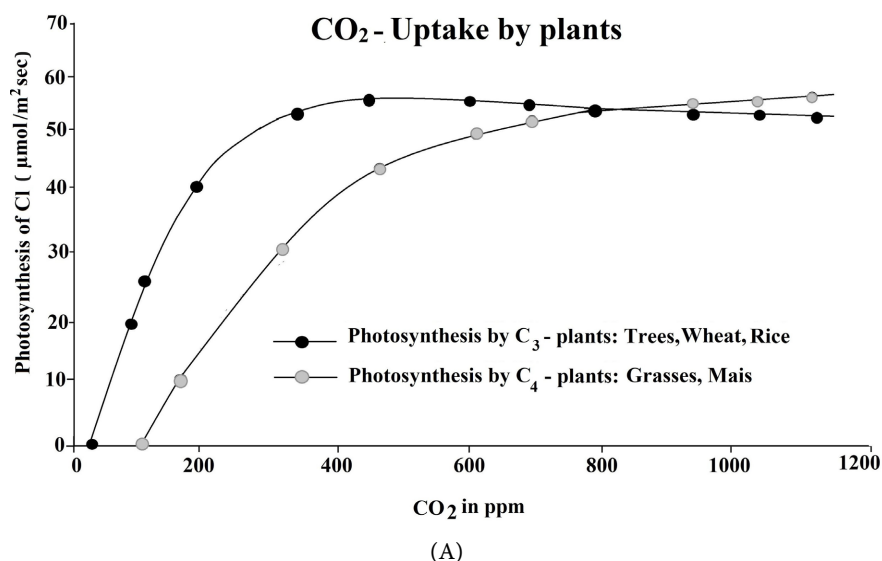


Figure 15. Photosynthesis and magmatism/degassing [58] [59] [73]. (A) Photosynthesis ends by $55 \mu\text{mol}/\text{m}^2\text{sec}$ and beyond 1100 CO₂ ppm [73]. (B) Linear decreases of pH, with increasing pCO₂ atm. [64] [69].

The reason of positive $\delta^{13}\text{C}$ excursion does not lay only in the temperature but also in the concentrations of $\delta^{13}\text{C}$ in phytoplankton, comp. the Ordovician K-bentonite formation [19] [20].

Phosphorite on the Outer Jordanian Platform

Along the upwelling zone of the Tethys, the phosphorite belt of the near Middle East covers the marginal platform from Upper Campanian to Maastrichtian [32] [33]. In Central Jordan the sequence exposes more than ten carbonate-chert-phosphorite cycles. The lateral facies distribution mirrors the vertical sequence on the platform from distal to proximal environments (shale → phosphorite shale → phosphorite limestone → chert → diverse carbonate lithofacies [32].

As main source material phytoplankton and vertebrate remnants provide Fluor-Apatite ($\text{Ca}_5(\text{F}, \text{Cl}, \text{OH})(\text{PO}_4, \text{CO}_3)_3$) in solution by rising pH and surface temperature. After the decay of phytoplankton (end of photosynthesis, decreas-

ing pH and Eh, negative climate forcing), apatite precipitates via pore water in colloidal/microcrystalline mode early diagenetically to grains and nodules at or close to the sedimentary surface [64] [70].

The cyclicity of the lithofacies types are interpreted as caused by volcanic events accompanied by change of climate forcing, sea level undulation, tuff and volatiles (pH, Eh).

4. Conclusions (Figures 13-15)

Magmatism agetates as a Major Driving Force for the development of Geodynamic Cycles concerning sea level (tidal dissemination), MORB, subduction, magnetism, mountain building, organic carbon (TOC), biocalcification, and marine clastics [8], thereby Moon Recession Rate may play a questionable role [74]; change at 220, 153, 70, and 58 Ma [8].

Degassing of LIPs, dykes/sills and rifting (greenhouse gases including CH_3Cl and CH_3Br and their acids cause positive climate forcing ($+\text{Wm}^2$) with regard to T, pH, Eh; pCO_2 , metal toxicity, photosynthesis, mass extinction [4] [15] [18] [20] [46] while subduction-related explosive island arc glass-bearing tuff volcanism (andesitic signature) direct Negative Climate Forcing ($-\text{Wm}^2$) relating to pH, Eh, TOC, photosynthesis, pCO_2 , mineral transformation/neoformation (volcanic glass, K-montmorillonite) by aerosols, tuff/ash and clouding [9] [20].

These drivers affected/directed/controlled lithofacies types formation throughout the Late Cretaceous on the Jordanian Platform in the case of chert, porcellanite, chalk, clay mineralogy (montmorillonite), skeleton substance (calcite, aragonite, opal), as well as their rapid change of interbedding.

The last 2 Ma, prior to the KPgB (66.04), expose several warming up-pulses [56] (Figure 10) during rising pCO_2 (800 to 1800 μatm) and falling pH (7.7 to 7.4) accompanied by at least two extinctions at 66.25 Ma (~start of the Deccan LIP) and at 66.04 Ma (Chicxulub Impact) with regard to benthic and pelagic species [56] [58].

It shouldn't be underestimated that the impact just provided additional aerosols and outfall sources in the rock column of ~2900 m carbonate/sulfate rocks and ~30 km thick granitoid basement rocks of the target area [75].

Furthermore, track change at Reunion (67.7 Ma) and at Puerto Rico (67.5 Ma) [8] coincide with warming-up pulses at Seymour, Antarctica [56].

Thus, the data make plausible that the "KPgB" represents rather a Transitional Zone based on Cumulative Effects, which took place.

Closing Statement

There is no reason to hesitate for applying the GAIA Principle [76] [77], well known in the fields of Biology also to the Geosciences:

"GAIA is merely a useful name for a worldwide phenomenon: the regulation of temperature, acids-bases equilibrium, and gas composition.

GAIA is the total of inter-agitating ecosystems that form a unique powerful system on Earth.

GAIA is in her complete symbiogenetic magnificence of her being: expansive, cunning, esthetic, very ancient and extremely resistant.”

Lynn Margulis, Biologist, trans. Schneider.

Acknowledgements

We are grateful to Kjell, and Brigitte Paris and Olaf Schneider for digital support. Thanks are also extended to Prof. Dr. Ikhlas Al-Hejoj and to Mrs. Arwa Al-Tarawneh for their help in preparing the figures.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Wilson, M. (1992) Magmatism and Continental Rifting during the Opening of the South Atlantic Ocean: A Consequence of Lower Cretaceous Super-Plume Activity? *Geological Society, London, Special Publications*, **68**, 241-255.
<https://doi.org/10.1144/gsl.sp.1992.068.01.15>
- [2] Turner, S., Regelous, M., Kelley, S., Hawkesworth, C. and Mantovani, M. (1994) Magmatism and Continental Break-Up in the South Atlantic: High Precision ⁴⁰Ar-³⁹Ar Geochronology. *Earth and Planetary Science Letters*, **121**, 333-348.
[https://doi.org/10.1016/0012-821x\(94\)90076-0](https://doi.org/10.1016/0012-821x(94)90076-0)
- [3] Price, N.J. (2001) Major Impacts and Plate Tectonics. Routledge, 354 p.
- [4] Svensen, H.H., Torsvik, T.H., Callegaro, S., Augland, L., Heimdal, T.H., Jerram, D.A., *et al.* (2017) Gondwana Large Igneous Provinces: Plate Reconstructions, Volcanic Basins and Sill Volumes. *Geological Society, London, Special Publications*, **463**, 17-40. <https://doi.org/10.1144/sp463.7>
- [5] Abdelmalak, M.M., Planke, S., Polteau, S., Hartz, E.H., Faleide, J.I., Tegner, C., Jerram, D.A., Millett, J.M. and Myklebustet, R. (2018) Break-Up Volcanism and Plate Tectonics in the NW Atlantic. *Tectonophysics*, **760**, 229-251.
- [6] Dobretsov, N.L., Vernikovskiy, V.A., Karyakin, Y.V., Korago, E.A. and Simonov, V.A. (2013) Mesozoic-Cenozoic Volcanism and Geodynamic Events in the Central and Eastern Arctic. *Russian Geology and Geophysics*, **54**, 874-887.
<https://doi.org/10.1016/j.rgg.2013.07.008>
- [7] Larson, R.L. (1995) Die Superplume-Episode in der Mittleren Kreidezeit. *Spektrum der Wissenschaft*, No. 7, 48-52.
- [8] Brink, H. (2006) Do the Global Geodynamic Cycles of the Phanerozoic Represent a Feedback System of the Earth and Is the Moon Involved as an Acting External Force? *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, **157**, 17-40.
<https://doi.org/10.1127/1860-1804/2006/0157-0017>
- [9] Schmincke, H.U. (2000) Vulkanismus. Darmstadt (Wissenschaftliche Buchgesellschaft), 264 p.
- [10] Haq, B.U. and Al-Qahtani, A.M. (2005) Phanerozoic Cycles of Sea-Level Change on the Arabian Platform. *GeoArabia*, **10**, 127-160.
- [11] Schmidt, H.V. (1974) Erdgeschichte. Sammlung Götschen, de Gruyter, 246 p.
- [12] Schneider, W. and Salameh, E. (2012) Did Major Impacts Affect Sedimentolog-

- ic/sequence-Analytical Pattern of the Early Palaeozoic Sedimentary Systems of Jordan, Arabian Plate? *Open Journal of Geology*, **2**, 241-252.
<https://doi.org/10.4236/ojg.2012.24024>
- [13] Schneider, W. and Salameh, E. (2020) Phanerozoic Quartz Arenite Formation and Sequence-Analytical Patterns: Indirectly Relating to Major Impacting and Super Plume Volcanism, Jordan, Arabian Plate. *Open Journal of Geology (OJG)*, **10**, 13-52.
- [14] Schneider, W. and Salameh, E. (2022) The Permian-Triassic Transitional Zone: Jordan, Arabian Plate; Linked to Siberian Large Igneous Province and Neo-Tethys Breakup Degassing via Climate Forcing, Atmospheric Hazard and Metal Toxicity. *Open Journal of Geology*, **12**, 472-503. <https://doi.org/10.4236/ojg.2022.126023>
- [15] Augland, L.E., Ryabov, V.V., Vernikovsky, V.A., Planke, S., Polozov, A.G., Callegaro, S., *et al.* (2019) The Main Pulse of the Siberian Traps Expanded in Size and Composition. *Scientific Reports*, **9**, Article No. 18723.
<https://doi.org/10.1038/s41598-019-54023-2>
- [16] Schneider, W. and Salameh, E. (2023) Effects on Sedimentary Processes via Upper Triassic Climate Forcing Caused by Multiple Impacting and Large Igneous Provinces (LIP)-Rifting/degassing: Jordanian Platform/Arabian Plate and Germanic Basin/Central Europe. *Open Journal of Geology*, **13**, 136-170.
<https://doi.org/10.4236/ojg.2023.132007>
- [17] Hodych, J.P. and Dunning, G.R. (1992) Did the Manicouagan Impact Trigger End-of-Triassic Mass Extinction? *Geology*, **20**, 51-54.
[https://doi.org/10.1130/0091-7613\(1992\)020<0051:dtmite>2.3.co;2](https://doi.org/10.1130/0091-7613(1992)020<0051:dtmite>2.3.co;2)
- [18] Heimdal, T.H., Jones, M.T. and Svensen, H.H. (2020) Thermogenic Carbon Release from the Central Atlantic Magmatic Province Caused Major End-Triassic Carbon Cycle Perturbations. *Proceedings of the National Academy of Sciences*, **117**, 11968-11974.
- [19] Armstrong, H.A., Turner, B.R., Makhoul, I.M., Weedon, G.P., Williams, M., Al Smadi, A., *et al.* (2005) Origin, Sequence Stratigraphy and Depositional Environment of an Upper Ordovician (Hirnantian) Deglacial Black Shale, Jordan. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **220**, 273-289.
<https://doi.org/10.1016/j.palaeo.2005.01.007>
- [20] Ballo, E.G., Augland, L.E., Hammer, Ø. and Svensen, H.H. (2019) A New Age Model for the Ordovician (Sandbian) K-Bentonites in Oslo, Norway. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **520**, 203-213.
<https://doi.org/10.1016/j.palaeo.2019.01.016>
- [21] Ormö, J., Sturkell, E., Alwmark, C. and Melosh, J. (2014) First Known Terrestrial Impact of a Binary Asteroid from a Main Belt Breakup Event. *Scientific Reports*, **4**, Article No. 6724. <https://doi.org/10.1038/srep06724>
- [22] Hussein, M.I. (1989) Tectonic and Deposition Model of Late Precambrian-Cambrian Arabian and Adjoining Plates. *AAPG Bulletin*, **73**, 1117-1131.
<https://doi.org/10.1306/44b4a54b-170a-11d7-8645000102c1865d>
- [23] Jarrar, G.H. (1986) Late Proterozoic Crustal Evolution of the Arabian-Nubian Shield in the Wadi Araba Area, SW-Jordan. *Geologisches Jahrbuch Reihe B, Band B. 61*, E. Schweizerbart, Stuttgart, 3-87.
- [24] Jarrar, G., Wachendorf, H. and Zellmer, H. (1991) The Saramuj Conglomerate: Evolution of a Pan-African Molasse Sequence from Southwest Jordan. *Neues Jahrbuch für Geologie und Paläontologie-Monatshefte*, **1991**, 335-356.
<https://doi.org/10.1127/njgpm/1991/1991/335>

- [25] Jarrar, G., Wachendorf, H. and Saffarini, G. (1992) A Late Proterozoic Bimodal Volcanic/Subvolcanic Suite from Wadi Araba, Southwest Jordan. *Precambrian Research*, **56**, 51-72. [https://doi.org/10.1016/0301-9268\(92\)90083-z](https://doi.org/10.1016/0301-9268(92)90083-z)
- [26] Jarrar, G., Wachendorf, H. and Zachmann, D. (1993) A Pan-African Alkaline Pluton Intruding the Saramuj Conglomerate, South-West Jordan. *Geologische Rundschau*, **82**, 121-135. <https://doi.org/10.1007/bf00563275>
- [27] Burgath, K.P., Hagen, D. and Siewers, U. (1984) Geochemistry, Geology, and Primary Copper Mineralization in Wadi Araba, Jordan. *Hannover, Geol. Jb.*, B 53, 3-53.
- [28] Jarrar, G.H. (1991) Petrology and Geochemistry of the Triassic Subvolcanic Suite from Central Jordan, E and NE of the Dead Sea. *Mu'tah Journal for Research and Studies*, **6**, 183-196.
- [29] Bandel, K. (1981) New Stratigraphical and Structural Evidence for Lateral Dislocation in the Jordan Rift Valley Connected with a Description of the Jurassic Rock Column in Jordan. *Neues Jahrbuch für Geologie und Paläontologie-Abhandlungen*, **161**, 271-308. <https://doi.org/10.1127/njgpa/161/1981/271>
- [30] Amireh, B.S. (1993) Three Paleosols of the Nubian Series of Jordan: Climatologic, Tectonic and Paleogeographic Implications. *Dirasat*, **20B**, 33-62.
- [31] Powell, J.H., Humphreys, B. and Moh'd, B.Kh. (1990) Hardground Development at the Base Mujib Chalk Member (Wadi Um Ghudran Formation), Senonian of Central and South Jordan. *Proceedings 3rd Jordanian Geological Conference*, Amman, 3-5 April 1988, 251-282.
- [32] Abed, A.M. and Kraishan, G.M. (1991) Evidence for Shallow-Marine Origin of a "Monterey-Formation Type" Chert-Phosphorite-Dolomite Sequence: Amman Formation (Late Cretaceous), Central Jordan. *Facies*, **24**, 25-37. <https://doi.org/10.1007/bf02536839>
- [33] Abed, A.M. and Amireh, B.S. (1999) Sedimentology, Geochemistry, Economic Potential and Palaeogeography of an Upper Cretaceous Phosphorite Belt in the Southeastern Desert of Jordan. *Cretaceous Research*, **20**, 119-133. <https://doi.org/10.1006/cres.1999.0147>
- [34] Mimran, Y. (1972) The Tayasir Volcanics: A Lower Cretaceous formation in the Shomeron, Central Israel. *Geological Survey of Israel Bulletin*, No. 52, 9 p.
- [35] Garfunkel, Z. and Derin, B. (1988). Reevaluation of Latest Jurassic-Early Cretaceous History of the Negev and the Role of Magmatic Activity. *Israel Journal of Earth-Sciences*, **37**, 43-52.
- [36] Bender, F. (1975) Geology of the Arabian Peninsula, Jordan Professional Paper 560-I.
- [37] ten Brink, U.S., Rybakov, M., Al Zoubi, A.S., Hassounah, M., Frieslander, U., Batayneh, A.T., *et al.* (1999) Anatomy of the Dead Sea Transform: Does It Reflect Continuous Changes in Plate Motion? *Geology*, **27**, 887-890. [https://doi.org/10.1130/0091-7613\(1999\)027<0887:aotdst>2.3.co;2](https://doi.org/10.1130/0091-7613(1999)027<0887:aotdst>2.3.co;2)
- [38] Abdallah S. Al-Zoubi, A.S. and Abu-Hamattah, Z.S.H. (2009) Geological Evolution of the Jordan Valley. *Journal of the Virtual Explorer*, **32**, Paper 10.
- [39] Cohen, Z. (1976) Early Cretaceous Buried Canyon: Influence on Accumulation of Hydrocarbons in Helez Oil Field, Israel. *AAPG Bulletin*, **60**, 108-114. <https://doi.org/10.1306/83d9228f-16c7-11d7-8645000102c1865d>
- [40] Amireh, B.S. (1997) Sedimentology and Palaeogeography of the Regressive-Transgressive Kurnub Group (Early Cretaceous) of Jordan. *Sedimentary Geology*, **112**,

- 69-88. [https://doi.org/10.1016/s0037-0738\(97\)00024-9](https://doi.org/10.1016/s0037-0738(97)00024-9)
- [41] Jacobshagen, V. (1994) Orogenic Evolution of the Hellenides: New Aspects. In: *Active Continental Margins—Present and Past*, Geol. Rundschau 83, Springer, 249-256.
- [42] Schneider, W., Bode, S. and Oppermann, A. (1998) Nappe Advance, Suture-Progradation, Erosion and Flysch-Composition in the Hellenides. *Neues Jahrbuch für Geologie und Paläontologie-Abhandlungen*, **209**, 349-379. <https://doi.org/10.1127/njgpa/209/1998/349>
- [43] German Stratigraphic Commission, Menning, M. and Hendrich, A. (2017) Stratigraphic Table of Germany Compact 2017. GFZ German Research Centre for Geosciences.
- [44] Amireh, B.S., Jarrar, G., Henjes-Kunst, F. and Schneider, W. (1998) K-Ar Dating, X-Ray Diffractometry, Optical and Scanning Electron Microscopy of Glauconies from the Early Cretaceous Kurnub Group of Jordan. *Geological Journal*, **33**, 49-65. [https://doi.org/10.1002/\(sici\)1099-1034\(199801/03\)33:1<49::aid-gj759>3.0.co;2-y](https://doi.org/10.1002/(sici)1099-1034(199801/03)33:1<49::aid-gj759>3.0.co;2-y)
- [45] Mutterlose, J., Wippich, M.G.E. and Geisen, M. (1997) Cretaceous Depositional Environment of NW Germany. *Bochner Geol. and Geotechn. Arbeiten* 46, 1-28.
- [46] Svensen, H.H., Jerram, D.A., Polozov, A.G., Planke, S., Neal, C.R., Augland, L.E., *et al.* (2019) Thinking about Lips: A Brief History of Ideas in Large Igneous Province Research. *Tectonophysics*, **760**, 229-251. <https://doi.org/10.1016/j.tecto.2018.12.008>
- [47] Abed, A.M. and Schneider, W. (1982) The Cenomanian Nodular Limestone Member of Jordan—From Subtidal to Supratidal Environments. *Neues Jahrbuch für Geologie und Paläontologie-Monatshefte*, **1982**, 513-522. <https://doi.org/10.1127/njgpm/1982/1982/513>
- [48] Abed, A.M. (1985) Emergence of Wadi Mujib Area (Central Jordan) during Lower Cenomanian and Its Regional Tectonic Implications. In: Dixon, J.E. and Robertson, A.E.F., Eds., *The Geological Evolution of the Eastern Mediterranean*, Spec. Publ. Geol. Soc., Blackwell Science Publishing, 848, p.
- [49] Abed, A.M. and El-Hiyari, M. (1986) Depositional Environments and Paleogeography of the Cretaceous Gypsum Horizon in West-Central Jordan. *Sedimentary Geology*, **47**, 109-123. [https://doi.org/10.1016/0037-0738\(86\)90074-6](https://doi.org/10.1016/0037-0738(86)90074-6)
- [50] Powell, J.H., Humphreys, B. and Moh'd, B.K. (1990) Hardground Development at the Base of the Muji Chalk Member (Wadi Um Ghudran F.), Senonian, of Central/Southern Jordan. *Proceedings 3rd Jordanian Geological Conference*, Amman, 3-5 April 1988, 251-262.
- [51] Khaled, H., Schneider, W. and Zachmann, D. (1990) Sedimentological and Geochemical Patterns of Jordanian Phosphate Deposits. *Proceedings 3rd Jordanian Geological Conference*, Amman, 3-5 April 1988, 146-175.
- [52] Abed, A.M. and Amireh, B.S. (1983) Petrography and Geochemistry of Some Jordanian Oil Shales from North Jordan. *Journal of Petroleum Geology*, **5**, 261-274.
- [53] Naji, F. (1983) Kalkiges Nanoplankton aus der Oberkreide und dem Alttertiär N Jordaniens (Mittel-Santon bis Mittel Eozän). *Geol. Jb. B* 55, 3-185.
- [54] Gradstein, E.M. and Ogg, J. (1996) The Phanerozoic Time Scale. *Episodes*, **19**, 3.
- [55] Gradstein, F.M., Ogg, J.G., Smith, A.G., Bleeker, W. and Lourens, L.J. (2004) A New Geologic Time Scale, with Special Reference to Precambrian and Neogene. *Episodes*, **27**, 83-100. <https://doi.org/10.18814/epiugs/2004/v27i2/002>
- [56] Peterson, S.V., Dutton, A. and Lohman, K.C. (2016) End-Cretaceous Extinction in Antarctica Linked to Both Deccan Volcanism and Meteoritic Impact via Climate Change. *Nature Communication*, **7**, Article ID: 123079.

- [57] Gradstein, F.M., Ogg, J.G. and Hilger, F.J. (2012) The Geological Time Scale. *Newletters on Stratigraphy*, **45**, 171-188.
- [58] Henehan, M.J., Ridgwell, A., Thomas, E., Zhang, S., Alegret, L., Schmidt, D.N., *et al.* (2019) Rapid Ocean Acidification and Protracted Earth System Recovery Followed the End-Cretaceous Chicxulub Impact. *Proceedings of the National Academy of Sciences*, **116**, 22500-22504. <https://doi.org/10.1073/pnas.1905989116>
- [59] Niebuhr, B. (2006) Multistratigraphische Gliederung der norddeutschen Schreibkreide (Coniac bis Maastricht), Korrelation von Aufschlüssen und Bohrungen. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, **157**, 245-261. <https://doi.org/10.1127/1860-1804/2006/0157-0245>
- [60] Schlanger, S.O., Arthur, M.A., Jenkyns, H.C. and Scholle, P.A. (1987) The Cenomanian-Turonian Oceanic Anoxic Event, I. Stratigraphy and Distribution of Organic Carbon-Rich Beds and the Marine $\Delta^{13}\text{C}$ Excursion. *Geological Society, London, Special Publications*, **26**, 371-399. <https://doi.org/10.1144/gsl.sp.1987.026.01.24>
- [61] Zimmerle, W. (1987) Vestiges of Volcanic Activity in Cretaceous of the Western Tethys. In: Wiedmann, J., Ed., *Cretaceous Symp.*, Schweizer Bart, 951-987.
- [62] Schneider, W. and Salameh, E. (2020) End-Cretaceous Quartz Arenite Formation in an Estuarine Environment under Brine Influence, N. Germany; Linked to both Deccan Volcanism and Chicxulub Impact Degassing during Climate Change. *Open Journal of Geology*, **10**, 1091-1118. <https://doi.org/10.4236/ojg.2020.1011053>
- [63] Millot, G. (1970) *Geology of Clays: Weathering, Sedimentology, Geochemistry*. Springer, 425 p.
- [64] Engelhardt, W.V. (1977) *The Origin of Sediments and Sedimentary Rocks. Part III. Sedimentary Geology*, Wiley, 359 p.
- [65] Nadeau, P.H. and Reynolds, R.G. (1981) Volcanic Components in Pelitic Sediments. *Nature*, **294**, 72-74.
- [66] Seibert, E. and Vortisch, W. (1979) Zur Stratigraphie, Petrologie und Genese einer Bentonit-Lage aus dem oberen Mittel-Turon (Oberkreide) des südöstlichen Münsterlandes. *Geologische Rundschau*, **68**, 649-679. <https://doi.org/10.1007/bf01820811>
- [67] Valetton, I. (1960) Vulkanische Tuffit-Einlagerung in der NW-deutschen Oberkreide. *Mitteilungen aus dem Geologischen. Staatsinstitut in Hamburg*, **29**, 26-41.
- [68] Brockamp, O. (1976) Nachweis von Vulkanismus in Sedimenten der Ober- und Unterkreide in Norddeutschland. *Geologische Rundschau*, **65**, 162-174.
- [69] Krauskopf, K.B. (1982) *Introduction to Geochemistry*. McGraw-Hill International, 617 p.
- [70] Füchtbauer, H. and Schmincke, H.U. (1974) *Sediments and Sedimentary Rocks. Part II, Sedimentary Petrology*. Wiley, 464 p.
- [71] Milliman, J.D. (1974) *Marine Carbonates. Recent Sedimentary Carbonates, Part 1*. Springer-Verlag, 375 p.
- [72] Bathurst, R.G.C. (1975) *Carbonate Sediments and Diagnosis. Developments in Sedimentology, No. 12*. Elsevier, 658 p.
- [73] Vahrenholt, F. and Lüning, S. (2021) *Unerwünschte Wahrheiten. LMV*, 352 p.
- [74] van Andel, T.H. (1994) *New Views on an Old Planet*. Cambridge University Press, 402.
- [75] Stöffler, D. (2002) Bedrohung aus dem Weltall-Asteroiden und Kometen. An den

Fronten der Forschung. Kosmos-Erde-Leben. Verhandlungen der Gesellschaft Deutscher Naturforscher und Ärzte, Vol. 122, 81-97.

- [76] Lovelock, J. (1992) GAIA: Die Erde ist ein Lebewesen. Bern, München, Wien 1992 (Scherz); 192 Seiten.
- [77] Margulis, L. (2021) Der Symbiotische Planet. Westend Verlag, Frankfurt, 172 p.