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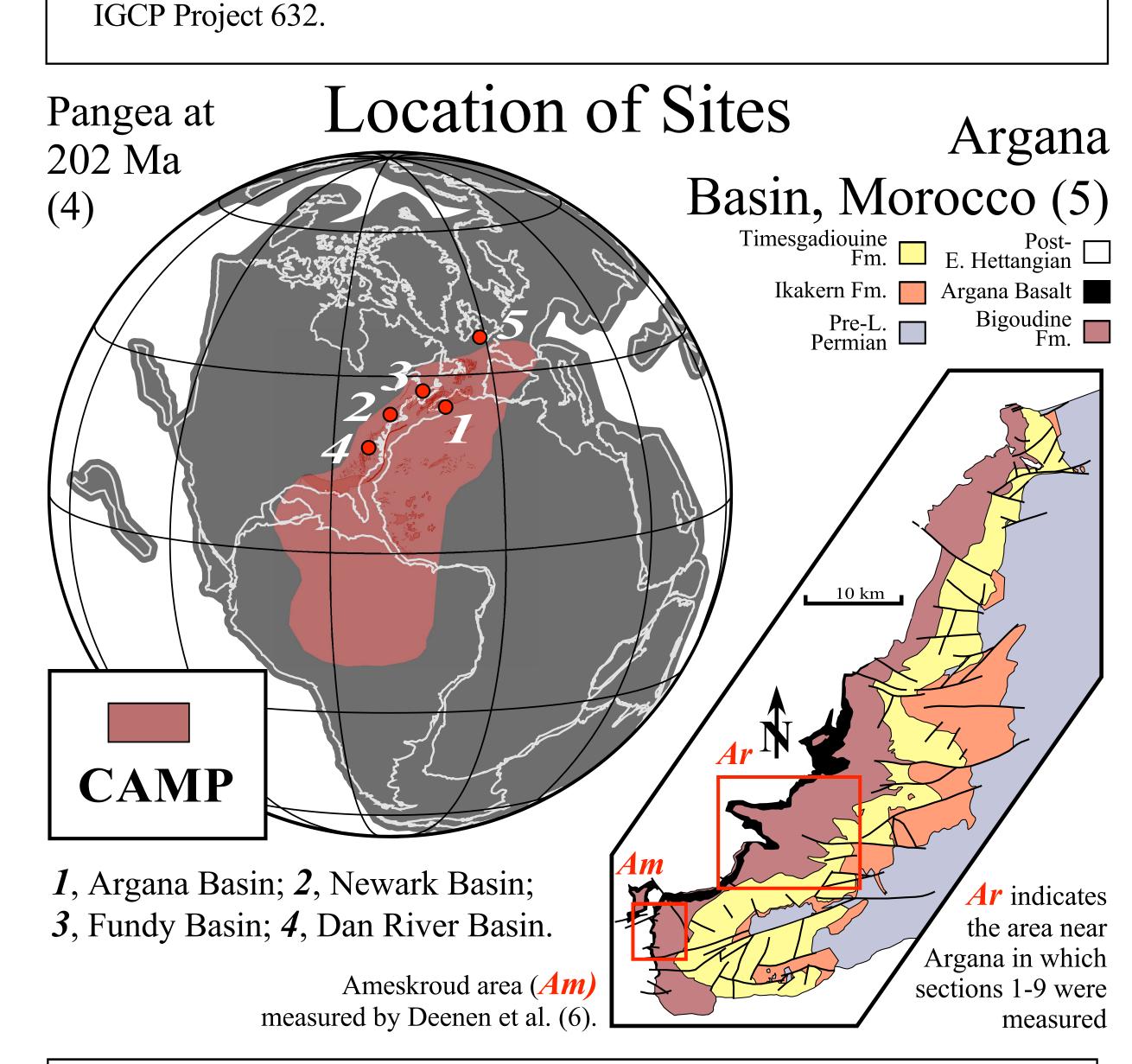
Tectonic, Astrochronostratigraphic, and Biostratigraphic Implications of the Faculte des Sciences Oujda Morocco Unidate Center Paleomagnetic Polarity Reversal Stratigraphy of the Late Triassic Bigoudine Formation (Argana Basin, Morocco)





Abstract

The Bigoudine Fm represents one of the most widespread facies of the Moroccan Triassic on land and on the shelf with close counterparts on the conjugate Scotian shelf and onshore Atlantic Canada. We describe a magnetic polarity stratigraphy for the Bigoudine based on >300 sampling sites spanning >990 m of composite section comprised of 10 outcrop sections averaging more than 25% overlap. These overlaps demonstrate the lateral continuity and repeatability of both the polarity transitions and cyclostratigraphy. Most of the sequence consists of cyclical saline playa lake facies with "sand patch" cycles, but perennial lake facies are also present as are significant eolian sandstones. The lower ~600 m has 10 very well-defined normal and reverse polarity zones corresponding to E13 to E17 in the Newark Basin APTS (1). The succeeding ~380 m approaching the overlying Argana basalts has a less well-defined polarity stratigraphy largely because of uncertainties in correlation between sections isolated by faults that we partly attribute to local salt tectonics and to a dramatic decrease in the variation in lacustrine facies. However, the basic polarity pattern is consistent with correlation to Newark Basin APTS chrons E18-E23n. Within a few meters of the base of the Argana basalts is the thin reverse zone E23r (2). Correlation between the Newark and Bigoudine polarity stratigraphies shows that many of the major lacustrine cycle sequences correlate as does the amplitude of the cyclicity larger scales. More surprising is that the accumulation rates in the two basins change in synchrony, given their separation by over 1000 km (pre-drift) on two different plates. The polarity stratigraphy also places constraints the sparse Argana biostratigraphy, showing, for example, that the co-occurrence of the spinocaudatans Shipingia gerbachmanni and Gregoriusella polonica from the basal Bigoudine Fm. cannot be uniquely indicative of an uppermost Norian age as supposed (3) because the Argana source bed unambiguously correlates to lower member I (lower E14n) in the Newark basin - 10 Myr older than the latest Norian (1). Funded by LDEO Climate Center and NSF 9317227, 0310240, 0753496. This is a contribution to UNESCO-IUGS



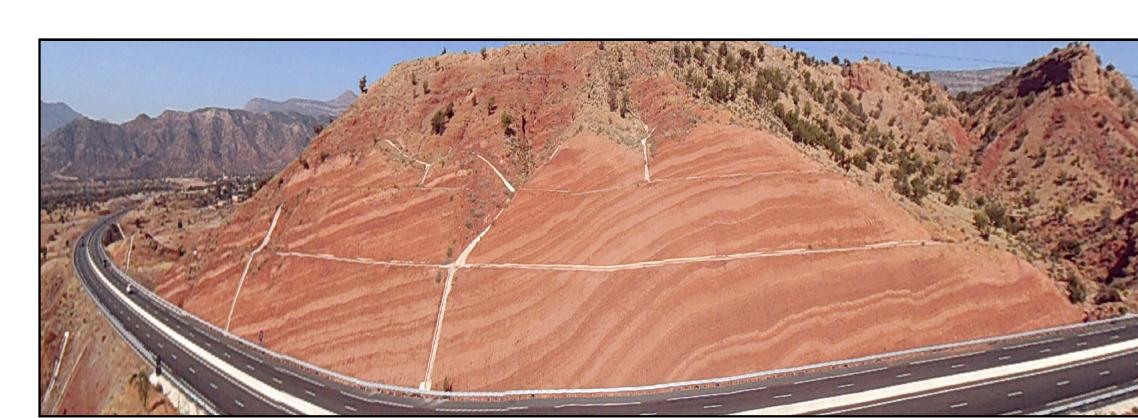
Argana Basin Stratigraphy (5,7,8)

Age	Cartoon Members	Formations stratigraphy Lithology Environments
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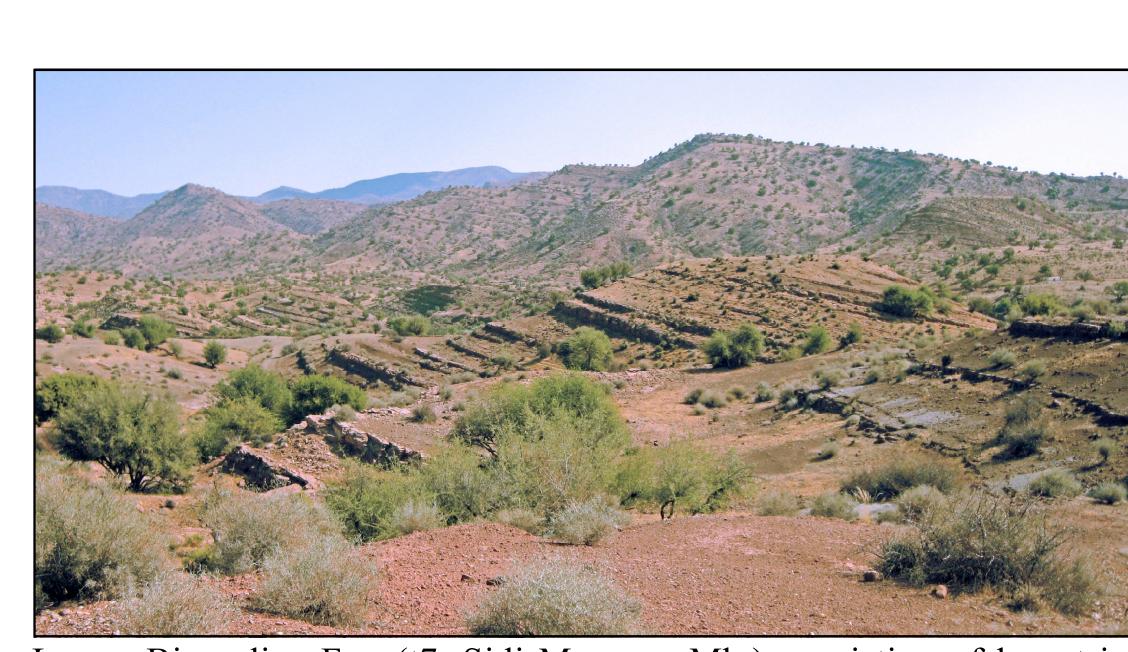
3000 -	SSIC	Sinemurian		Tamarout Fm.	RIFT	Carbonates	marine
-	Į∑ŀ	Hettangian	t9	Ameskroud Fm.		Red and minor gray, cyclical mudstones	Lacustrine and playa, some hypersaline
-	-	Rhaetian	ßt	Alemzi Basalt Tasguint Basalt	TS IV		Lava flows, minor sedimentary interbeds and ashes, fissure fills
2500 -	SSIC		\Aït Khattab			Red, gray, and black cylcical mudtsones and sandstones	Saline pans and playa minor non-saline lacustrine
- - 2000 -	LATE TRIASSIC	Norian	Hasseine (t8)	Bigoudine Fm.	TS III	Almost entirely red, cyclical mudstones and sandstones	Playa and hypersaline playa, minor non-saline lacustrine
_ _	-		Sidi Mansour (t7) Tadrat			Red and minor gray, cyclical mudstones and sandstones Red sandstone and	Lacustrine and playa, some hypersaline Eolian to fluvial
			O uadou		~~~~	minor conglomerate	minor playa
1500 -	TO LATE	Carnian - Anisian?	Irohalen (t5)	Timesgadiouine Fm.	TS II	Red and purple, cyclical mudstones, and sandstones	Lacustrine, to fluvial
1000 -	MIDDLE		Aglegal (t4)			Red mudstones interbeded with sandstones	Fluvial, minor lacustrine
_			√ Tanamert_ (t3)			red volcanoclastic conglomerates	Fluvial
500 -	MIAN		Tourbihine (t2)	Ikakern Fm.	TS I	Red intra-formational conglomerates and sandstones	Fluvial, minor lacustrine
0	LATE PERMIAN	Tartarien	Aït Driss (t1)			Red and purple conglomerate	Fluvial

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Uppermost Bigoudine Fm. [t8, Hasseine Mb. (playa, red mudstones, below) and Ait Khattab Mb. (pollen-bearing, lacustrine white and red mudstone layers, above with chron E23r)] and overlying Tazguint Basalt [lower Argana Basalt (\(\beta t\)].



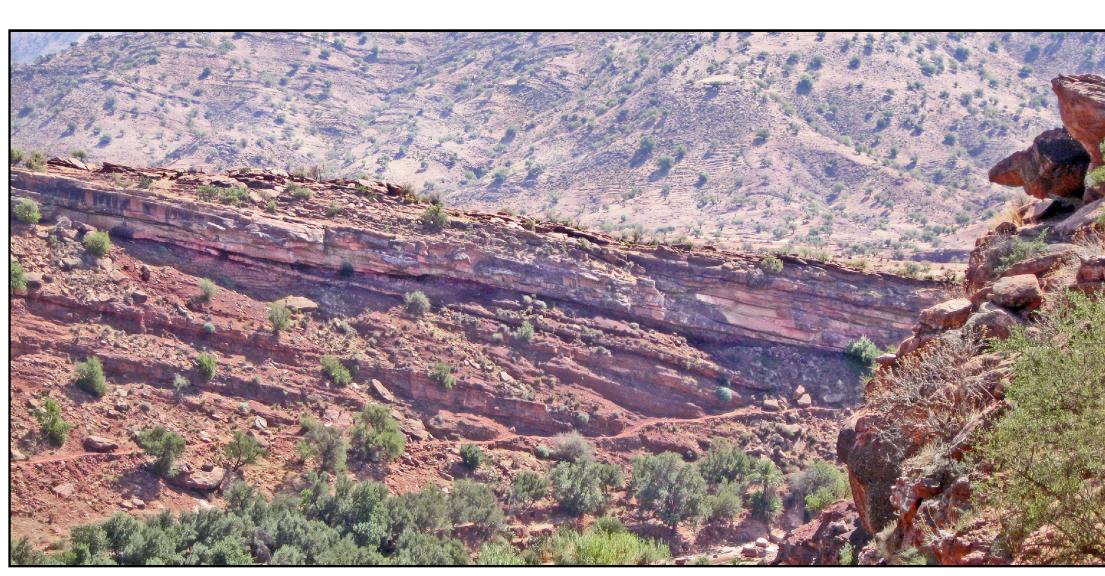
Middle Bigoudine Fm. (t8, Hasseine Mb.) consisting of red mudstones and sandstones in saline playa, sand-patch cycles (9).



Lower Bigoudine Fm. (t7, Sidi Mansour Mb.) consisting of lacustrine cyclical red gray mudstones and sandstones in lacustrine and saline playa, sand-patch cycles.



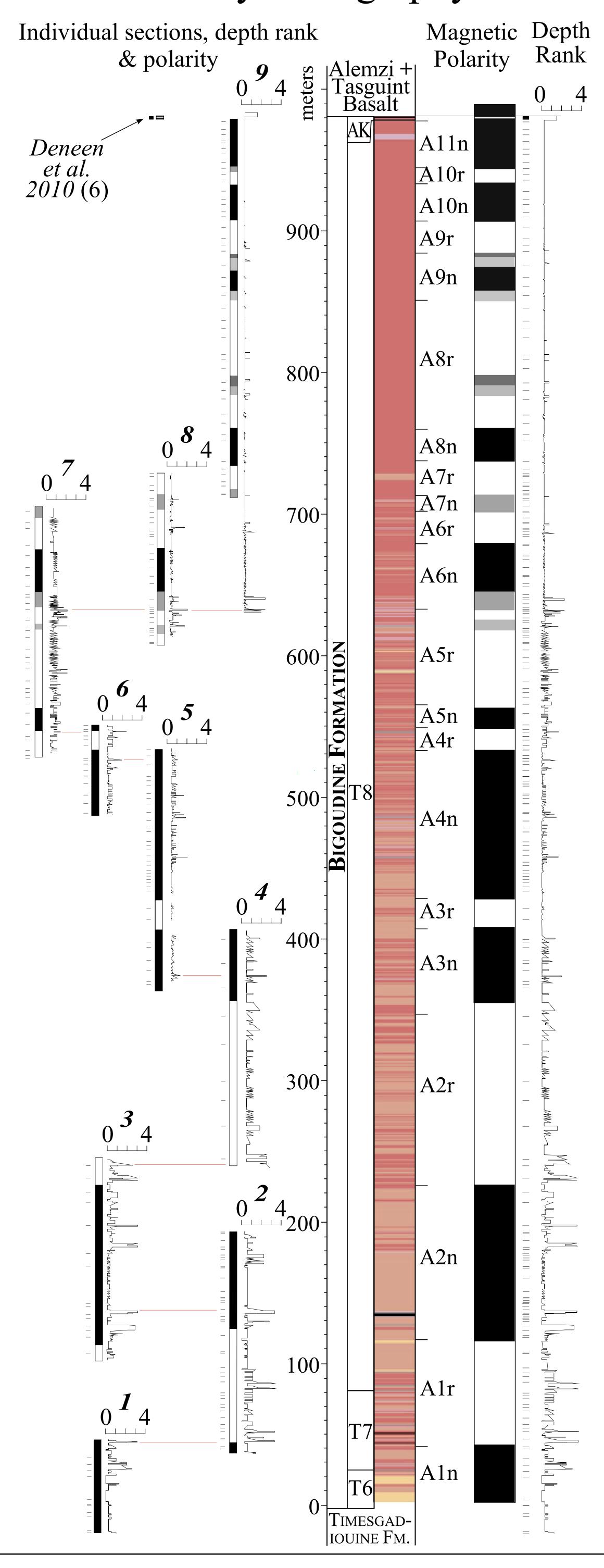
Basal Bigoudine Fm. (t6, Tadrat Ouadou Mb.) consisting mostly of eolian (seen here) (10,11) and fluvial sandstones unconformably overlying the Timesgadiouine Fm (t5).

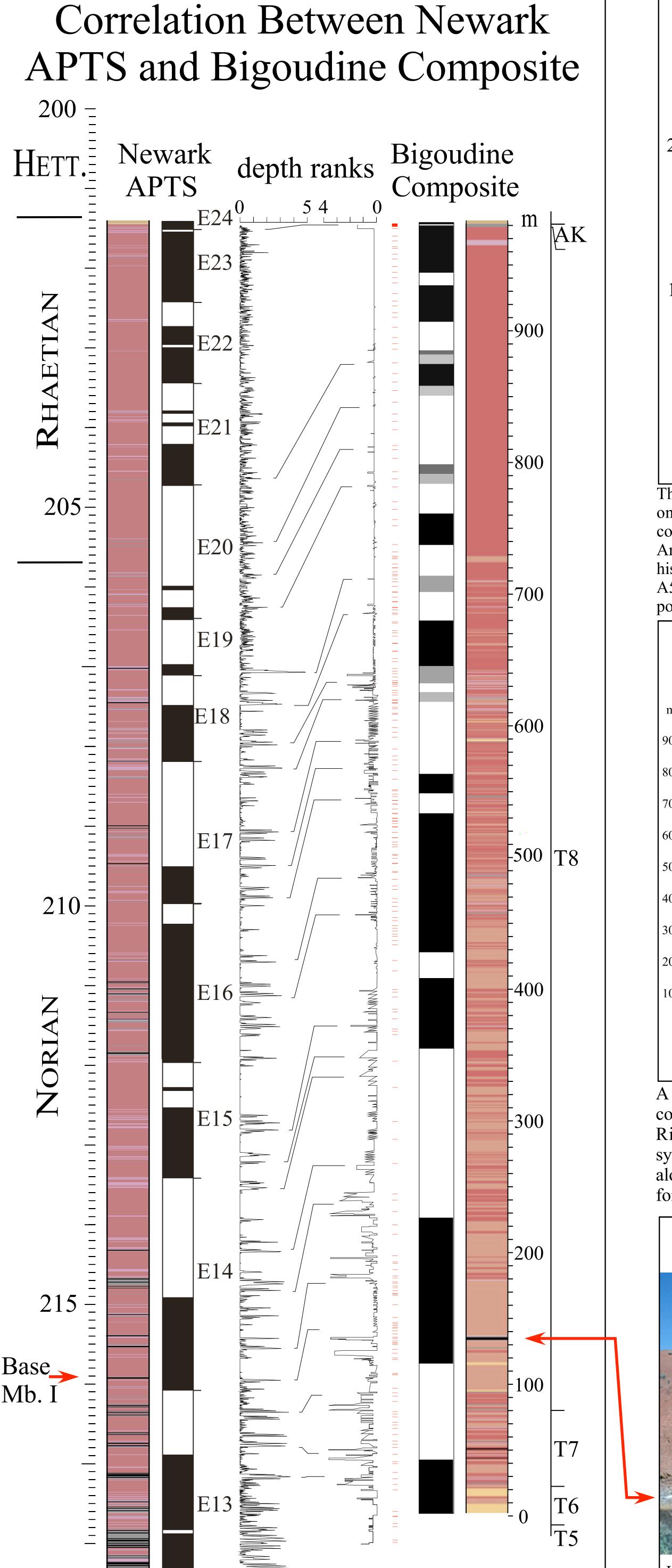


Gentle angular unconformity between fluvial and eolian basal Bigoudine (above: t6, Tadrat Ouadou Mb.) and shallow lacustrine and fluvial Timesgadiouine (below: t5, Irohalen Mb.) formations.

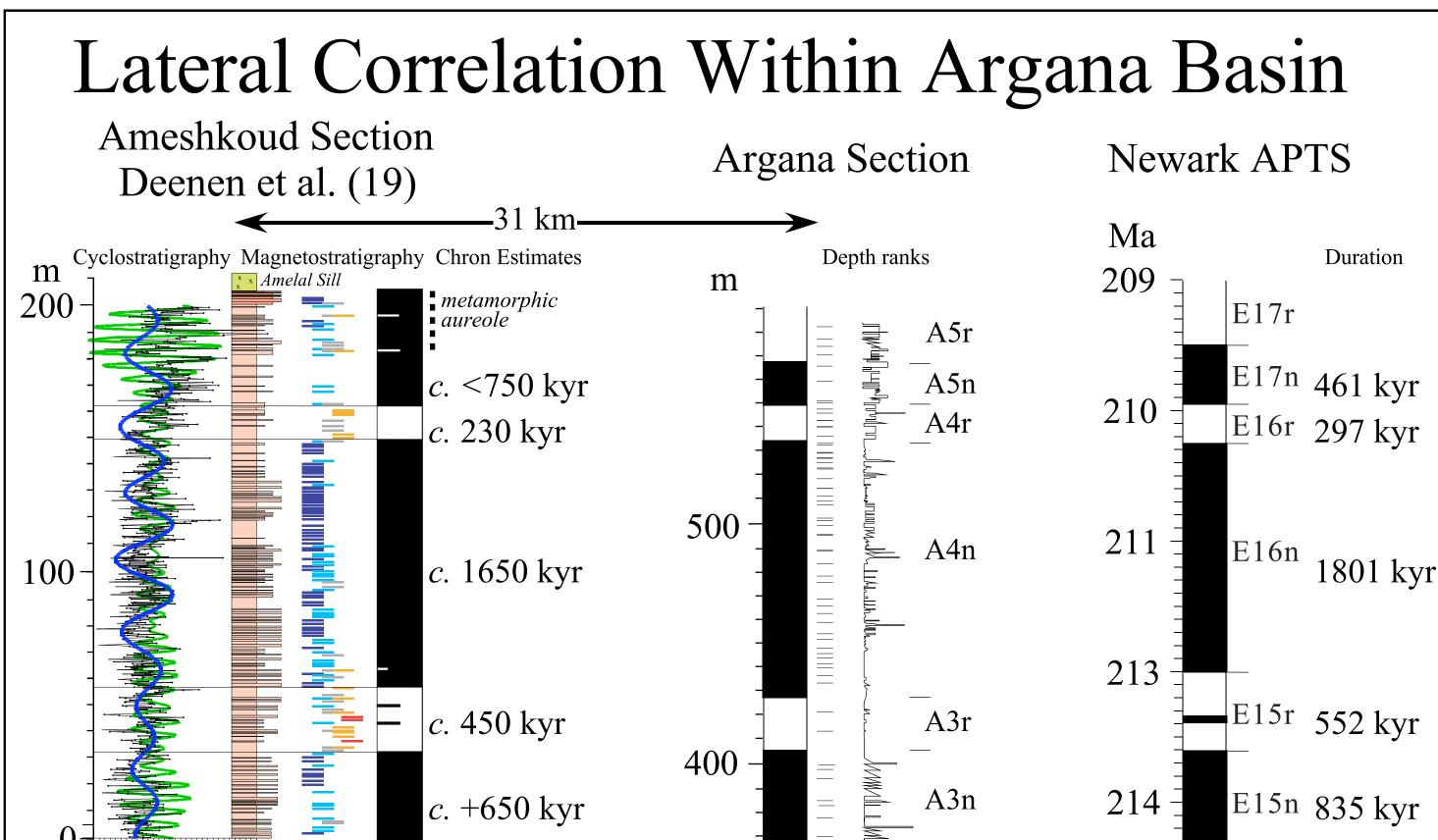
The composite Bigoudine section (below) was compiled from 9 sections near the village of Argana with a total of 330 outcrop sites each with 1-3 block or plug samples. Each sample underwent complete thermal demagnetization to 680°C in 10 or more to isolate magnetization components. IRM acquisition and thermal demagnetization analysis on a representative suite of samples shows that hematite with a maximum unblocking temperature of 680°C is the main magnetic mineral. The high unblocking temperature, characteristic remanent magnetization (ChRM) was usually isolated using principal component analysis and is characterized by a bimodal distribution of relatively shallow directions interpreted as normal (black) and reverse (white) magnetizations. Chron boundaries are placed by convention between samples of different polarity and the few less easily interpreted samples are indicated as gray. Correlation between sections was based on litholgical marker beds usually tested by polarity reversals.

Bigoudine Sections and Composite Polarity Stratigraphy

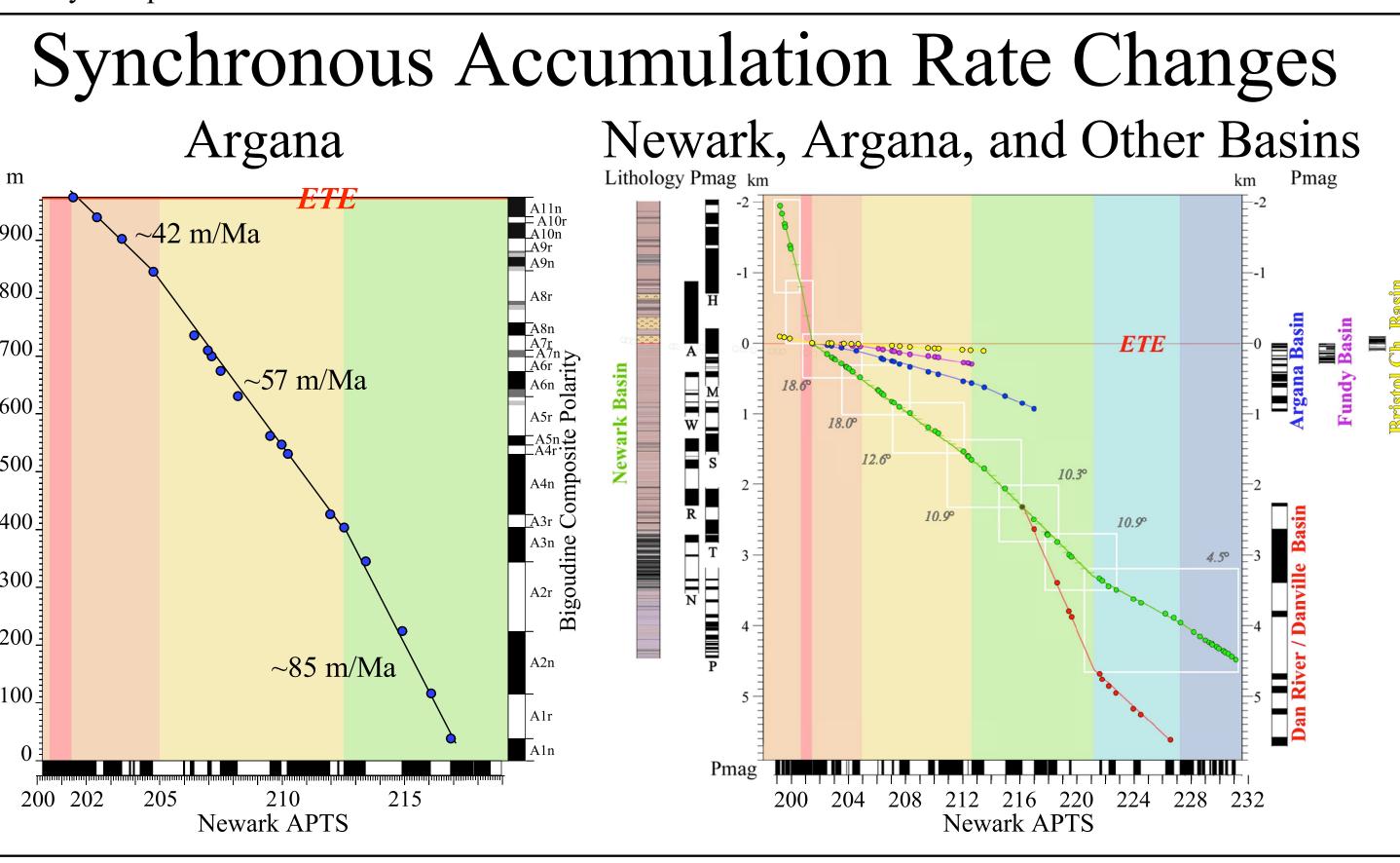




Correlation of the composite Bigoudine polarity sequence to the Newark basin APTS (12, 13, 14) is relatively straightforward, although the Argana Basin sedimentary facies is much more arid and evidently with much lower accumulation rates. Comparison of the facies indicative of relative lake depth [depth ranks (15) indicates correlation between individual lake depth cycles as well as corresponding general trend to more arid facies due to the northward translation of central Pangea during the Late Triassic. Especially clear is the correlation between Newark APTS chrons E13 - E17 and Argana basin A1 - A5 and additionally between the polarity sequence described by Deenen et al., (6) at the top of the Bigoudine Fm. and Newark APTS chrons E22-E24 which includes the tiny E23r polarity zone just below the palynological end-Triassic extinction event.



The robustness of the polarity sequence within the Argana Basin is testable by the lateral repeatability seen not only by the correlation between the overlap zones between the individual sections making up the Bigoudine composite, but also between a "floating" section below the Amelal Sill described by Deenen et al. (19) in the Ameshkoud area 31 km south of where the composite section was derived. Deenen's (19) interpreted durations for his chrons based on a Milankovitch interpretation of his magnetic susceptibility measurements correlating to A3n-A5n in the Bigoudine composite and the Newark APTS chrons E15-E17 are within sampling error and the normal polarity overprint of the Amelal Sill.



A perhaps surprising result of the correlation between the Newark-Hartford APTS and the Bigoudine composite are the apparently synchronous changes in accumulation rates, changes also seen in the Dan River (16), Fundy (17), and Bristol Channel (18) basins. Accumulation rate changes were thus synchronized in rift basin on three different tectonic plates, minimally over distances of over 3200 km along the rifting axis and 600 km across the rift axis over a period of at least 30 million years. This argues for for relatively simple and direct plate motion control of extension.

Spinocaudatan Biostratigraphy Kozur & Weems (20) and Weems & Lucas (21) argue that there is a significant hiatus in the upper pre-CAMP strata throughout the Central Atlantic rift sequences, notably in the Newark, Fundy, and Argana basins. The gap, comprising most of the Rhaetian, is based largely on the ranges of spinocaudatans (clam shrimp). Weems & Lucas (21) argue that two taxa Shipingia gerbachmanni

ing their eponymous zones (A). Absence of these zones in the Newark Supergroup is the main reason for supposing there is a hiatus. Weems & Lucas (21) identify the same two taxa in an assemblage of clam shrimp from the Bigoudine Fm. (collected by PEO and MET) that they cite as evidence of the supposed hiatus. However, the polarity stratigraphy shows that this assemblage correlates with base of member I of the Passaic Fm at 215.9 Ma (B), more than 10 Myr older than the Norian-Rhaetian boundary, far older than any possible Rhaetian strata. The two possible explanations are: 1) the taxa are misidentified; or 2) the ranges of the taxa are greater than supposed. Either way, the evidence for the hiatus is undermined by the Bigoudine polarity stratigraphy.

and Gregoriusella polonica are present in the European late Rhaetian defin-

Elwain et al (1999) Science 285:1386; 2 Schaller et al (2011) Science 331:1404; 3 Rampino et al (1988) Ann Rev Earth Planet Sci 16:73; 4 Whiteside et al (2010) PNAS 107:6721: 5 Tixeront (1973) Notes Mem Sery Geol Maroc 249:147: 6 Deenen et al (2010) EPSL 291:113: 7 Olsen et al (2003) in Brown (ed.) Conventional Core Workshop, GSA (NE) and Atlant Geosci Soc p51-63; **8** El Hachimi et al (2011) in Van Hinsbergen et al (ed) Geol Soc, Lond, Spec Pub 357:167; **9** Smoot & Olsen (1988) in Manspeizer (ed) Triassic-Jurassic Rifting and the Opening of the Atlantic Ocean, Elsevier p. 249-274; **10** Et-Touhami & Olsen (2003) GSA Abst Prog 35(3):16; **11** Letourneau et al (2015) GSA Abst Prog 47(3):56; **12** Kent & Olsen (1999) JGR 104:12,831; **13** Olsen & Kent (1999) Phil Trans Roy Soc Lond (A) 357:1761; **14** Kent et al (2016) Earth Sci Rev (in press); **15** Olsen & Kent (1996) PPP 122:1; **16** Kent & Olsen (1997) GSA Bull. 109(3):366; **17** Kent & Olsen (2000) EPSL 179(2):31; **18** Hounslow et al (2004) PPP 213:331; **19** Deenen et al (2011) in Van Hinsbergen et al. Geol Soc, Lond, Spec Pub 357:195; **20** Kozur & Weems (2010), in Lucas (ed) Geol. Soc Lond, Spec Pub 334:315; 21 Weems & Lucas (2015) in Sullivan & Lucas (eds) Fossil Record 4. New Mex Mus Nat Hist Sci Bull 67:303.