# Deccan Volcanism and the KT Mass Extinction: A New Perspective on Global Effects of Volcanism*

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## Expanded Abstract

Recent studies indicate that Deccan volcanic eruptions occurred in three main phases with the initial relatively small phase-1 eruptions at 67.5 m.y., the main phase-2 with ~80% eruptions over a relatively short time interval in magnetic polarity C29r, and the last phase-3 in the early Danian base C29n. Here we report the global biotic and environmental effects of each of these Deccan volcanic phases that demonstrate not only the strong cause-and-effect relationship with the Cretaceous-Tertiary (KT) mass extinction, but also the climate and environmental changes associated with the initial phase-1 and the last phase-3 in the early Danian that resulted in the long delayed biotic and environmental recovery. Data are based on ONGC wells from the Krishna-Godavari and Cauvery Basins and from KT sequences of the Tethys Ocean.

The first direct link between Deccan volcanism and the KT mass extinction was established in Rajahmundry quarries (Andhra Pradesh) and ONGC wells from the Krishna-Godavari Basin where the world's longest lava flows (known as upper and lower Rajahmundry traps) are recovered extending >1500 km across the Indian continent and out into the Bay of Bengal (Keller et al., 2008). Biostratigraphic studies of thick intertrappean sediments reveal earliest Danian (zones P0-P1a) planktic foraminifera overlying the lower traps, which places the (KT) mass extinction at the end of the main phase-2 Deccan volcanism. Corroboration of these results is found in central India (Jhilmili, Chhindwara District, Madhya Pradesh) and Meghalaya (Keller et al., 2009a,b; Gertsch et al., in prep.). ONGC wells reveal the nature of the mass extinction in intertrappean sediments between four lava flows of the lower trap basalts in C29r. Preliminary results show that after the arrival of the first lava flow, over 50% of planktic foraminiferal species disappeared, after each subsequent basalt flow more species disappeared and the mass extinction was complete by the fourth and last flow. Deccan eruptions thus strongly indicate a cause-and-effect relationship with the KT mass extinction.

Beyond India, multi-proxy studies also place the main Deccan phase in the uppermost Maastrichtian C29r below the KTB, as indicated by a rapid shift in $^{187}Os/^{188}Os$ ratios in deep-sea sections from the Atlantic, Pacific, and Indian Oceans, coincident with rapid climate warming, coeval increase in weathering, a significant decrease in bulk carbonate indicative of acidification due to volcanic $SO_2$, and major biotic stress conditions expressed in species dwarfing and decreased abundance in calcareous microfossils (planktic foraminifera and nannofossils,(Figure 2). These observations indicate that Deccan volcanism played a key role in increasing atmospheric $CO_2$ and $SO_2$ levels that resulted in global warming and acidified oceans, respectively, increasing biotic stress that predisposed faunas to eventual extinction at the KTB.

Environmental consequences of these massive eruptions were likely devastating not just because of the dust cloud obscuring sunlight and causing short-term global cooling, but because of gas emissions, particularly $SO_2$ and $CO_2$. Sulfur dioxide gas released by volcanism and injected into the stratosphere forms sulfate aerosol particulates, which act to reflect incoming solar radiation and causes global cooling. Since sulfate aerosol has a short lifespan in the atmosphere, the cooling would be short-term (years to decades), unless repeated injections from volcanic eruptions replenish atmospheric sulfate aerosols and lead to a runaway effect. From Chenet et al. (2007, 2008) we know that Deccan volcanism occurred in a series of rapid, pulsed eruptions with each of the 30 largest pulses estimated to inject up to 150 GT of $SO_2$ gas, or the equivalent of the Chicxulub impact (e.g. 50-500 GT), over a very short time (decades). By this estimate the total Deccan eruptions injected 30 to 100 times the amount of $SO_2$ released by the Chicxulub impact. It is not just the sheer volume of $SO_2$ injection, but also the rapid succession of volcanic eruptions with repeated $SO_2$ injections that would have compounded the adverse effects of $SO_2$ leading to severe environmental consequences (e.g., cooling, acid rain, extinctions), preventing recovery and likely causing a run-away effect.

Although most studies have concentrated exclusively on the KT mass extinction and the main phase-2 of Deccan volcanism, initial studies show that both phase-1 and phase-3 also had major global effects on marine biota and climate. For example, the long delayed (500 ky) recovery of the marine ecosystem after the mass extinction has long been an enigma in KT studies. The clue to this delayed global recovery is found in ONGC wells of the K-G Basin where the last phase of Deccan volcanism in C29n immediately precedes the full recovery. Investigation of this delayed recovery through the Tethys Ocean (e.g., Israel, Egypt, Tunisia, Texas) reveals the presence of organic-rich sediments, *Guembelitria* blooms (80%) and a negative $\delta 13C$ shift that rivals the $\delta 13C$ shift at the KT mass extinction.

Even the comparatively minor phase-1 of Deccan eruptions left its global mark. Analysis of ONGC wells from the Cauvery Basin reveal the first link to the onset of Deccan volcanism in zone CF4 (~67.5 m.y.) based on ash fall and blooms of the disaster opportunist *Guembelitria cretacea*. Faunal analysis of the same interval in the eastern Tethys (Israel, Egypt, Tunisia) and Texas reveal correlative *Guembelitria* blooms that indicate strong adverse global effects associated with phase-1 Deccan volcanism (Adatte and Keller, in press). Continued studies of ONGC wells in the K-G and Cauvery Basins are needed to substantiate the emerging global scale of Deccan eruptions that ultimately led to the KT mass extinction and the long delayed recovery of the marine ecosystem.

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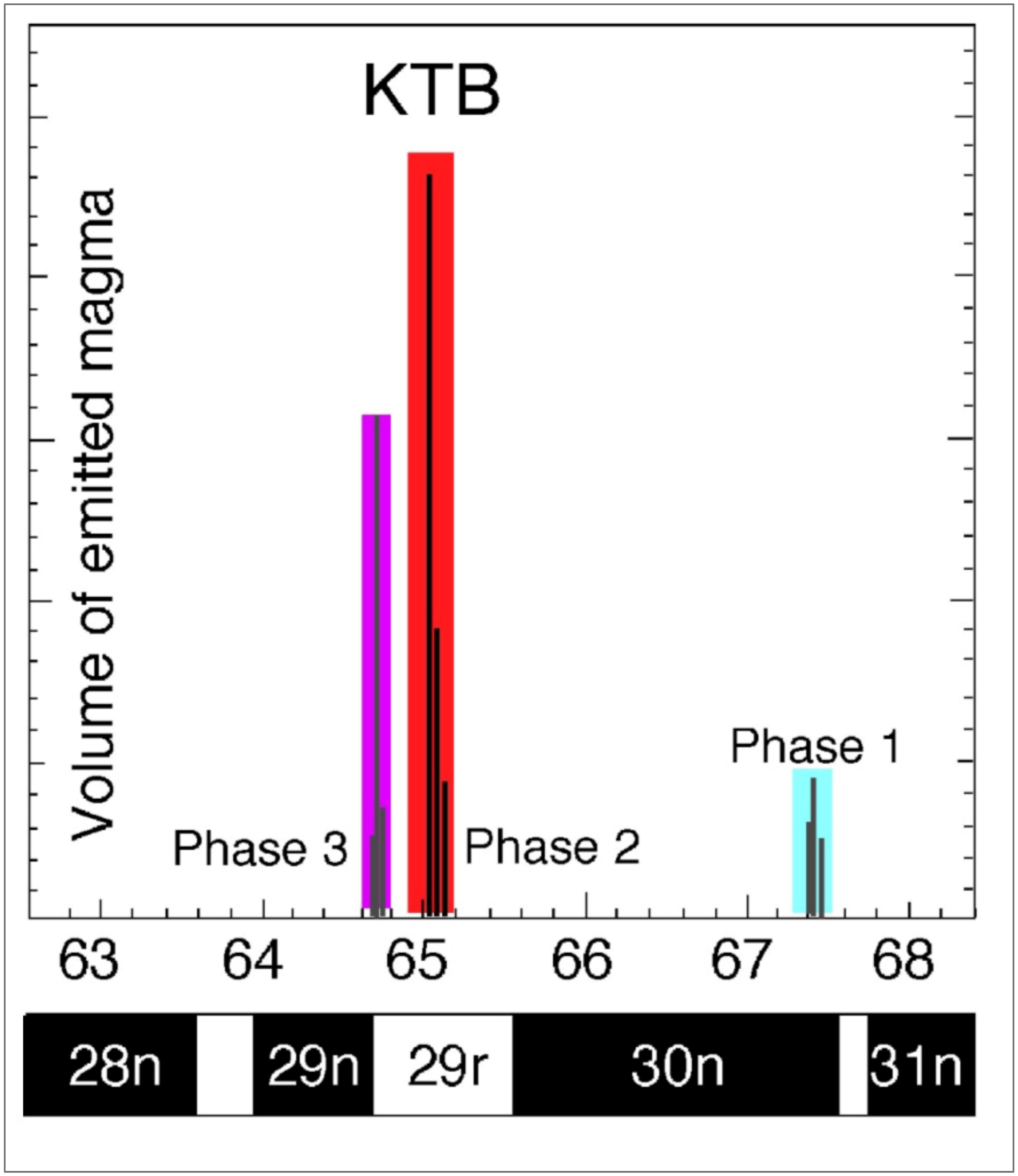


Figure 1a. Three phases of Deccan volcanism have been identified (Chenet et al., 2007, 2008) with the largest phase-2 ending with the KT mass extinction (modified from Chenet et al., 2007).

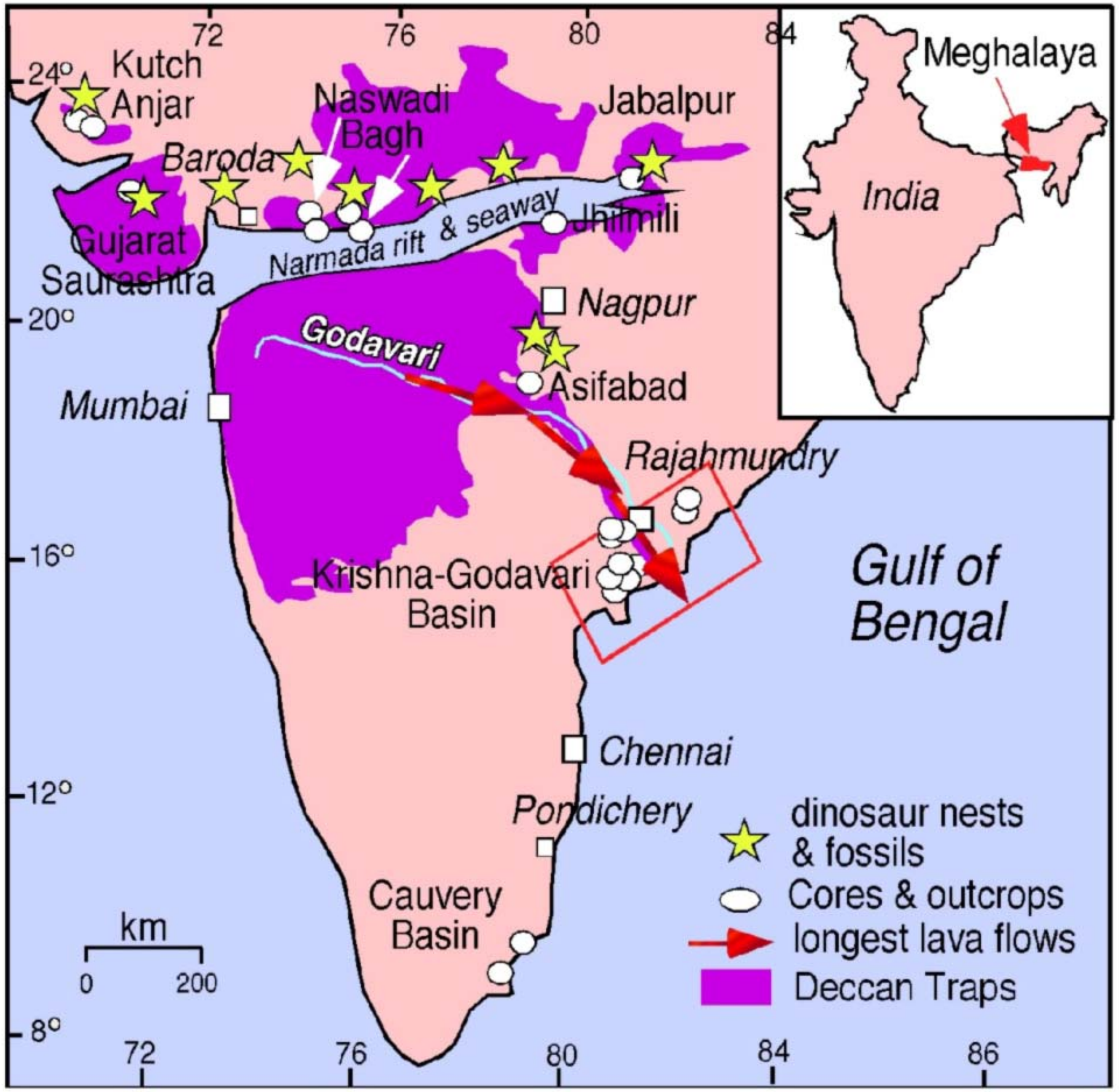


Figure 1b. The longest lava flows (>1500 km) known on Earth occurred during phase-2 and phase-3 eruptions; they outcrop in quarries of Rajahmundry and are known as lower and upper traps.

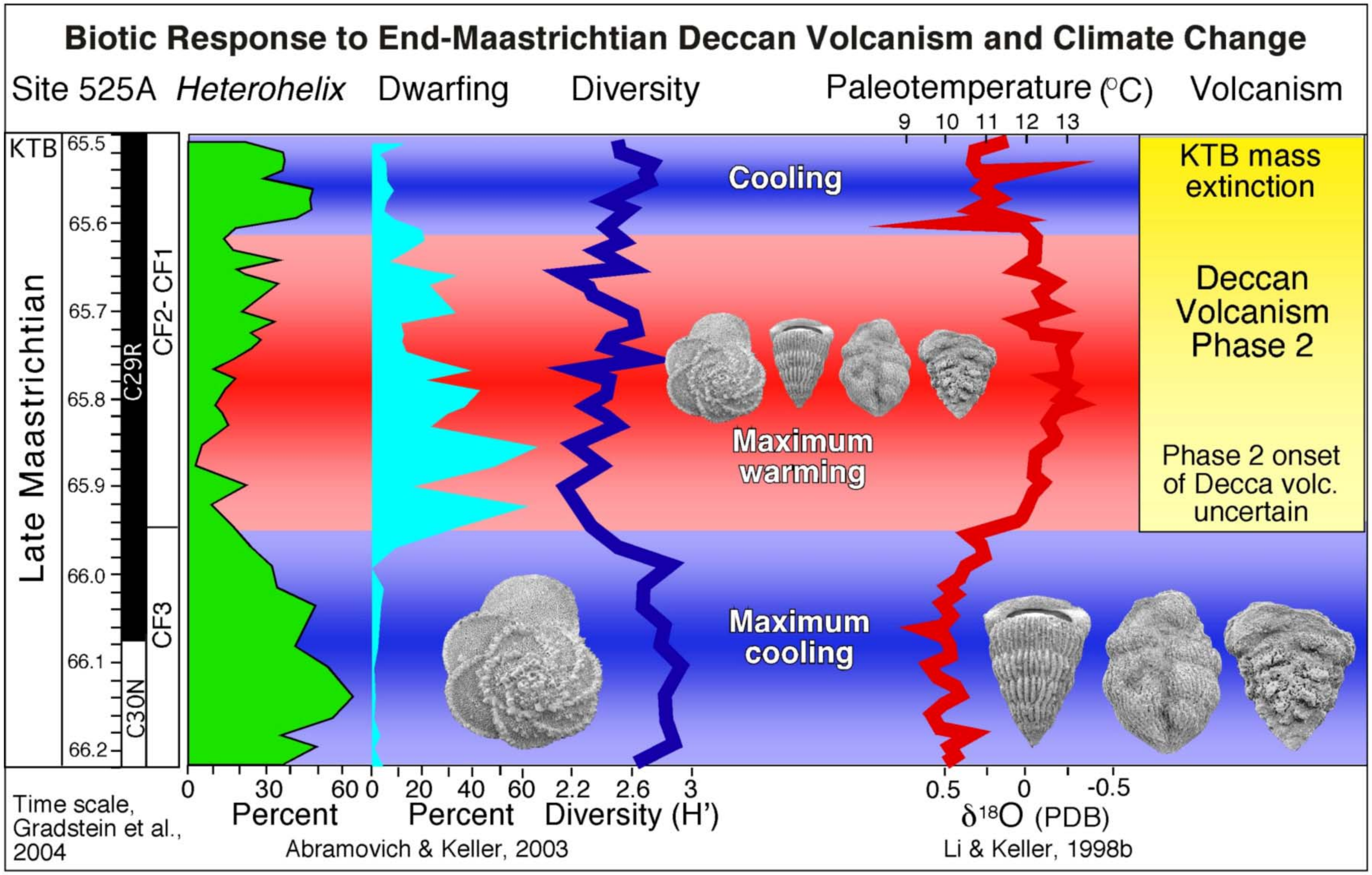


Figure 2. Species dwarfing (50% reduced size) during the latest Maastrichtian C29r warm event at DSDP Site 525 on Walvis Ridge, South Atlantic, is associated decreased diversity, decreased Heterohelix species abundance, and increased abundance of dwarfed specimens. Dwarfing is a direct result of biotic stress conditions during the climatic warming that may have been induced by Deccan volcanism. (modified after Abramovich and Keller, 2003).

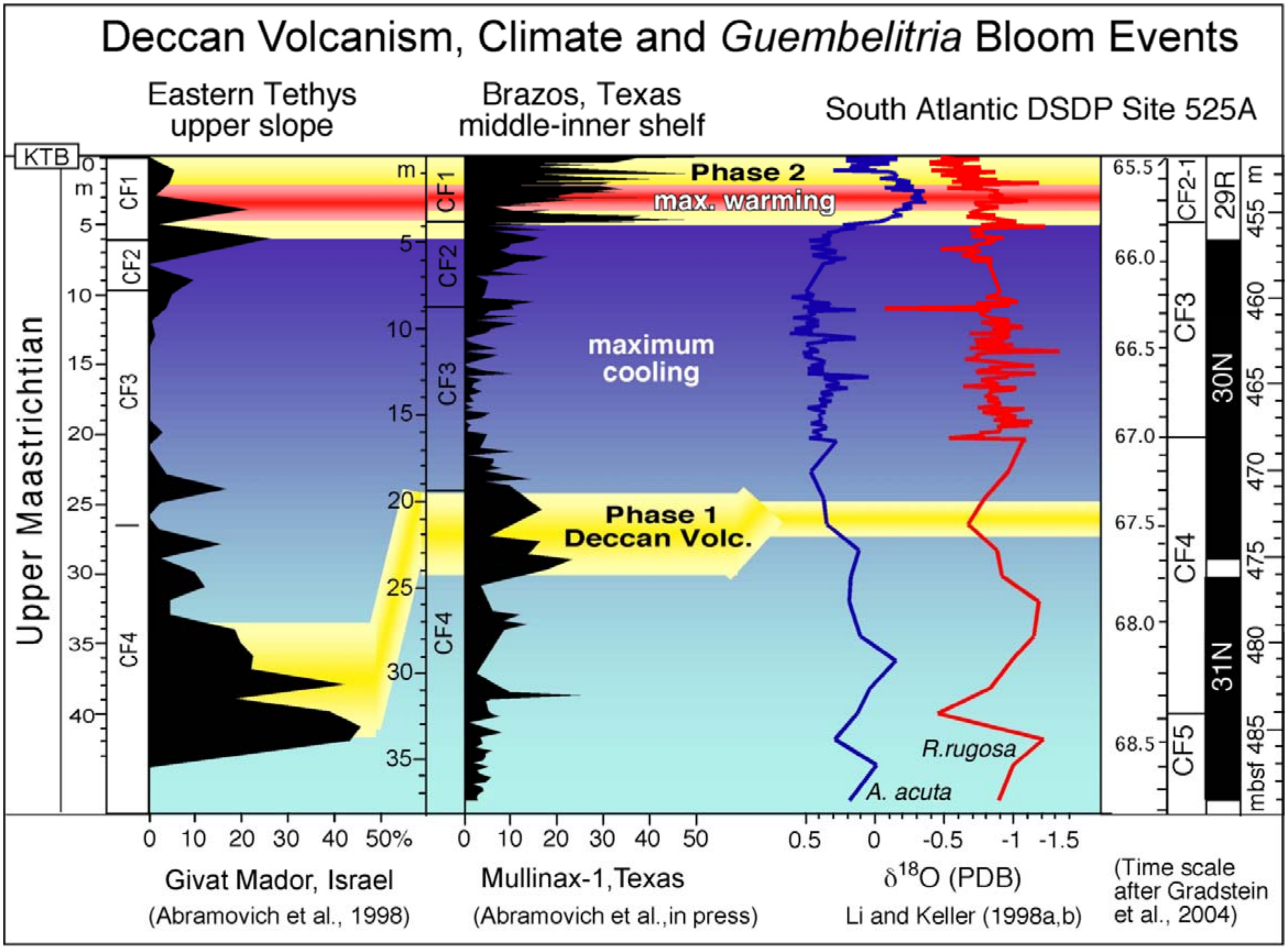


Figure 3. Stratigraphic correlation of Guembelitria bloom events in the upper Maastrichtian of the eastern Tethys (Israel) and Western Interior Seaway (Brazos, Texas) correlated with the climate record of South Atlantic DSDP Site 525A and Deccan volcanism phase-1 and phase-2. Note there are two major Guembelitria blooms in zones CF4 and CF2-CF1, which represent major environmental stress conditions correlative with the first two phases of Deccan volcanism. Similar Guembelitria blooms associated with high stress conditions have also been documented from Argentina and Indian Ocean DSDP Site 216 (Keller, 2003; Keller et al., 2007). (Modified after Abramovich et al., 2010)