Slice 26: Upper Zuni IV – middle Campanian – Selandian (Late Cretaceous – earliest Paleogene) – 81-58 Ma

This was the time of the rapid movement of India, formation of the Caribbean plate, active orogenesis, convergence in Tethys, inversion in Europe and mass extinction (Fig. 31).

Convergent Tectonics

Throughout the time period Africa was moving northwards closing the gap between its northern margin and the Taurus plate and causing a cessation (Campanian time) of spreading in the East Mediterranean (Ricou, 1996; Sengör & Natalin, 1996). The collision between Kirsehir, Sakariya and the Pontides (Yilmaz *et al*., 1997) closed the northern branch of Neotethys. The oceanic basins between Taurus and Kirsehir remained open. The northward movement of the Shatski terrane began closing of the proto-Black Sea (Kazmin, 1997).

According to Froitzheim *et al*. (1996), the collision between the Austroalpine units and the Briançonnais terrane in the Alps started in the early Paleocene. Latest Cretaceous-earliest Paleocene was also the time of the closure of the Pieniny Klippen Belt Ocean and the collision of the Inner Carpathians terranes with the Czorsztyn Ridge in the Carpathians (Golonka & Sikora, 1981; Birkenmajer, 1986; Winkler & Ślączka, 1992, Golonka *et al*., 1999). The primary shortening events in the Balkans occurred in Bulgaria (Sinclair *et al*., 1997). The Vardar Ocean was closed during Paleocene time (Sengör & Natalin, 1996).

Compressional episodes occurred along the African-Arabian plate margin. These events included thrusting in the Moroccan High Atlas, folding of the Syrian arc, compression in the Sinai area (Fizon de Lamotte *et al*., 1998. Moustafa & Khalil, 1990; Guiraud & Bellion, 1996) and inversion on the Central African Rift System.

Obduction of ophiolites on the Arabian margin was caused by the convergence of the Sanandaj-Sirjan with Arabian plates (Ricou, 1996; Guiraud & Bellion, 1996; Robertson & Searle, 1990). The exotic rocks of the Oman ophiolitic nappes reflect different stages of the evolution of the Tethyan Ocean and its branches from the Permian to the Cretaceous (Pillevuit *et al*., 1997). Ophiolites were also obducted in Turkey and emplaced on the Taurus block (Sengör & Natalin, 1996). Baluchistan collided with Eurasia. The movement of the Indian plate narrowed significantly the Neotethys in this region (Royer & Sandwell, 1989; Lawver *et al*., 1992).

At the Pacific margin the Kula plate was being subducted under Eurasia at a high rate of speed (Zonenshain *et al*., 1990). The East Sakhalin arc collided with the Eurasian margin. The Brooks-Herald fold-and-thrust belt developed in the northern part of Alaska and on the Eurasian shelf, north of Chukotka (Grantz *et al*., 1990, 1994). According to Parfenov (1992), in Late Cretaceous to Paleocene time, the active margin of the Pacific was displaced 300 km east, towards the Pacific Ocean. A subduction zone developed along the Kamchatka-Koryak volcanic belt. Further south, the subduction-accretionary terranes were sutured to Japan (Sengör & Natalin, 1996). South-dipping subduction developed along the southern margin of proto-South China Sea in South-East Asia north of Borneo (Lee & Lawver, 1994).

A volcanic arc existed along the Andean margin convergent margin, where the Farralon plate was subducted beneath the South American continent (Lamb *et al*., 1997). Eastward movement of the Caribbean arc between North and South America, as well as the subduction of the Proto-Caribbean oceanic crust beneath the advancing Greater Antilles island arc continued (Ross and Scotese, 1988). This arc collided with the Bahama platform during the latest Cretaceous, resulting in the capture of the Caribbean plate and the initiation of subduction along the Panama Arc (Scotese, 1991). The trapped Caribbean seafloor had been a part of the Farallon plate of the Pacific (Lawver & Gahagan, 1993). The Amiache-Chaucha terrane was accreted to South America (Pindell & Tubutt, 1995). The western North American Cordillera continued to compress during the Cretaceous and Cenozoic, until the Eocene. This compression resulted in thrusting and margin-parallel, transcurrent faulting (Oldow *et al*., 1990).

The Atlantic passive margins were uplifted (Wernicke & Tilke, 1989). The widespread inversion in the North Sea (Huyghe & Mugnier, 1994; Dronkers & Mrozek, 1991) and in Central Europe (P. Ziegler, 1988, 1990, 1994; Baldschuhn *et al*., 1991) could have been a result of the stress induced by the movement of Europe and ridge push from the Bay of Biscay spreading. The direction of the Late Cretaceous Subhercynian and Laramide structures (P. Ziegler, 1988, pl.16) was parallel to the Bay of Biscay and perpendicular to the Alpine-West Carpathian front, as well as to the future spreading in the North Atlantic, between Norway and Greenland. According to Baldschuhn *et al*.(1991), the Coniacian to Campanian time of inversion in north-western Germany did not coincide with the continent-continent collision events in the Alpine realm. Unternehr & Van Den Driessche (1977) argue that the North Sea compressive tectonics were not restricted to basin inversion, but instead involve crust and/or lithospheric buckling, and that there was a close connection between the North Atlantic opening and compression in the southern North Sea during the Late Cretaceous. The Eurekan Orogeny in the Arctic (Okulitch *et al*., 1998) was also a related event.

Extensional Tectonics

The Indian plate was moving rapidly, widening the Indian Ocean (Royer & Sandwell, 1989; Lawver *et al*., 1992). The direction of spreading in the Indian Ocean changed from NE to N. India drifted further away from Madagascar, opening the Mascarene Basin (Scotese, 1991). The movement of India over the Reunion hot spot resulted in the emplacement of large volumes of flood basalts, known as the Deccan traps (Coffin & Eldholm, 1994).

The location of Iceland between the Baffin Island and Greenland, approximately during the time span between 100 and 70 Ma (Lawver & Müller, 1994), resulted in the spreading of the Labrador Sea, rifting in the Baffin Bay and emplacement of volcanics on the western coast of Greenland (Gill *et al*., 1992, 1995; Holm *et al*., 1992, Larsen *et al*., 1992). The main line of spreading in the Atlantic realm, adjacent to Europe, extended from the Biscay Bay to Labrador Sea (see P. Ziegler, 1988; Huyghe & Mugnier, 1994). Spreading in the Makarov Basin was perhaps also related to the opening of the Labrador Sea. The Makarov spreading affected rifting in on the Eurasian continent, in the Zyrianka Basin (Bocharova *et al*., 1995). The Central and South Atlantic continue to widen (Golonka *et al*., 1994).

Rifting between Australia and New Zealand took place at Anomaly 33, about 80.2 Ma (Scotese, 1991). According to Lawver & Gahagan (1993), seafloor spreading originated between the Campbell Plateau and the Marie Byrd Land at about 84 Ma and then extended into the Tasman Sea region. Australia was drifting away from Antarctica.

The Central African rifts were rejuvenated once again. Movements of rifts on the Trans-African Fault occurred (P. Ziegler, 1993). Back-arc extension in East China contributed to the formation of East China Sea Basin (Kong, 1998). The northward movement of the Shatski terrane began the opening of the eastern Black Sea (Robinson *et al*., 1996).

Sea Level and Climate

The Upper Zuni IV supersequence began with a high sea-level, which slowly lowered, then dropped dramatically at the Danian-Thanetian boundary. Global greenhouse conditions continued, with hot, equable climates and generally humid continental, interior settings. Cooling occurred at the end of the time slice. Local aridity was associated with orographic effects. No evidence of extensive continental glaciation was recorded, although the polar temperatures were low enough to allow the formation of seasonal ice or even permanent glaciers (Frakes & Francis, 1990).

The uplifted African Atlantic margin created internal drainage and narrow continental margins. Marine transgression reached its maximum in North Africa, during Late Campanian time (Philip *et al*., 1996). A major mass extinction event happened took place during this time.

Carbonate Sedimentation

Carbonates occurred throughout the northern and southern hemisphere, reaching relatively high latitudes, up to almost 60 degrees. Similarly to the situation in Cenomanian and Turonian times, most carbonate sediment consisted of marls and chalks on broad shelf areas. According to Philip *et al*. (1996), the Late Campanian transgression left a large area covered by carbonate platforms over the African-Arabian plate. Chalks were widespread in Western and Eastern Europe including the North Sea area (P. Ziegler, 1982, 1988, 1990; Vinogradov, 1968b). Chalks were also present in the North America seaway north of Gulf of Mexico (Sloss *et al*., 1960). Carbonates and mixed carbonates-clastic facies were widespread in Central Asia and the West Siberian seaway (Vinogradov, 1968b, Ronov *et al*., 1989). Platform carbonates continue to accumulate on the north Indian margin, on Malvinas, on the New Guinea plate and the adjacent parts of Australia (Dercourt *et al*., 1993; Ronov *et al*., 1989; Cook, 1990). In the northern Tethys area, the Maastrichtian was a period of widespread development of carbonate platform. Carbonate flysch was deposited in the basinal areas. At the end of the time slice, a drastic collapse of carbonate platforms occurred (Philip *et al*., 1996) due to increased tectonic activity, which resulted in regression or drowning.