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Chronology and geodynamic setting of Cretaceous–Cenozoic rifting in West and Central Africa

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ABSTRACT

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The development of the Early Cretaceous to Palaeogene West and Central African rift system, which extends from Nigeria (Benue trough) to Kenya (Anza trough), can be related to the build-up of intraplate tensional stresses during the break up of Gondwana, which caused reactivation of pre-existing zones of lithospheric weakness. Repeated changes in the intraplate stress regime of Africa are reflected by phases of crustal extension alternating with episodes of compression. Many of these events can be correlated with changes in rates of seafloor spreading in the Central and South Atlantic oceans, as reflected in flowline patterns. The West and Central African rifts can be considered as typical 'passive' rifts which evolved in response to the build-up of intraplate stresses. However, the St. Helena hot spot appears to have been located beneath the Equatorial plate boundary at approximately 120 Ma and may have played an important role in weakening the lithosphere during extension.

Introduction

This summary aims at describing the various rifting phases which affected West and Central Africa during Mesozoic and Cenozoic times. It is based on papers presented in the West and Central African section of this volume. We define eight major tectonic and magmatic events and consider the relationships between them and the geodynamic evolution of the African plate; moreover, we attempt to show how rifting and orogenic phases, magmatism, thermal subsidence, uplift and basin inversion fit into an overall picture (Fig. 1).

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Permo-Triassic initial rifting episodes related to break up of Gondwana

The initial break up of Gondwana began during the Permo-Carboniferous and Triassic. Rifting concentrated on widely separated areas, namely on the eastern margin of Africa, along the axis of the future Central Atlantic ocean and in the Tethys domain. All these areas are characterized by rift-related magmatic events. In Southeast Africa, the onset of Karoo rifting is dated as Late Carboniferous and Permian (Lambiase, 1989); a strong Early Jurassic magmatic event occurred during the 190–200 Ma time interval (Dingle et al., 1983) and preceded the Late Jurassic split of Gondwana into a western and an eastern half. Along the northwestern margin of Africa, rifting commenced during the Middle Triassic and culminated, at the transition from the Triassic to the

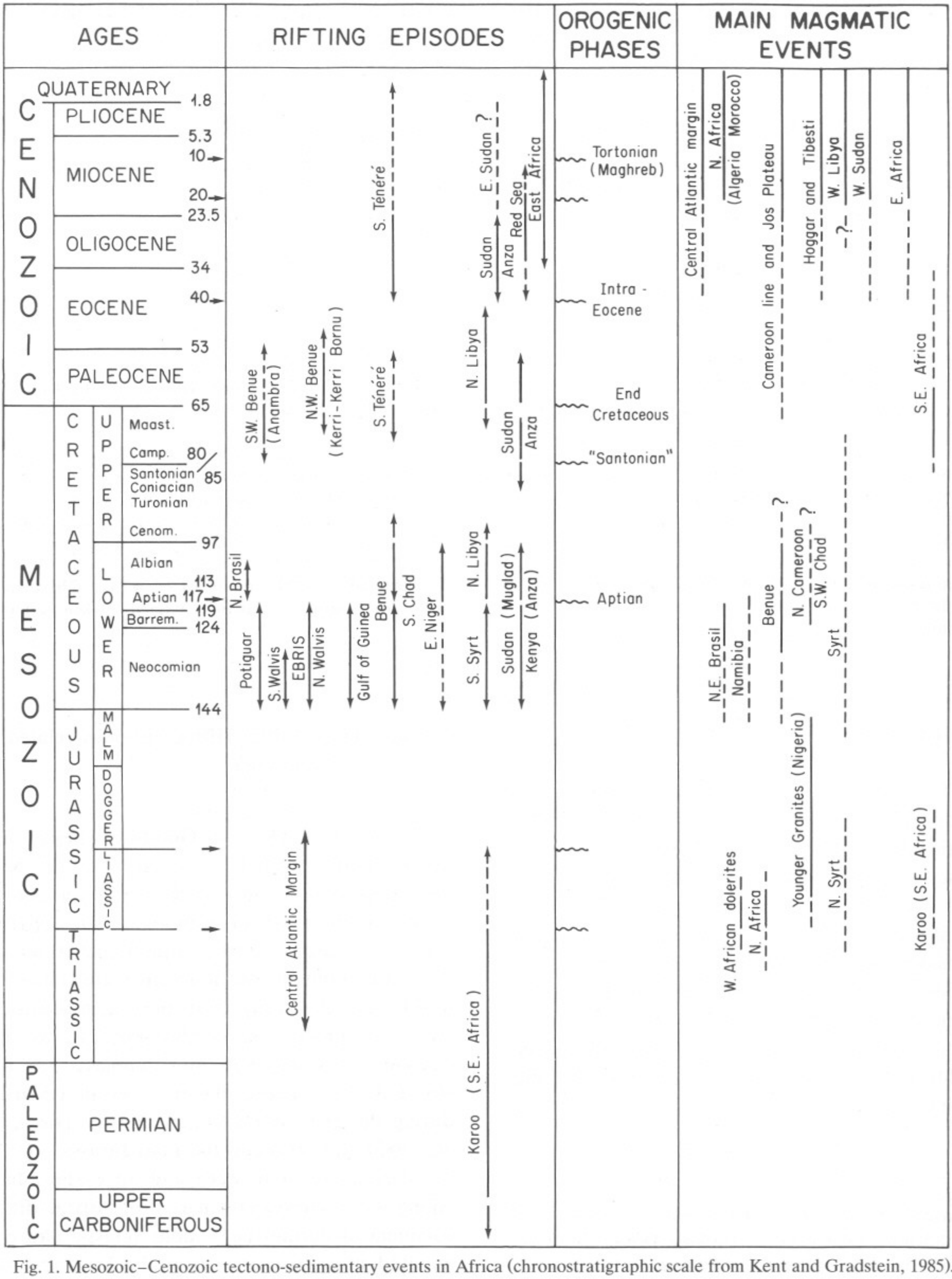

Fig. 1. Mesozoic–Cenozoic tectono-sedimentary events in Africa (chronostratigraphic scale from Kent and Gradstein, 1985).

Jurassic, with the intrusion of extensive dolerite dykes and sills. Such intrusions are reported from Spain to Liberia; they occupy a large area in the Taoudenni Basin where they yield $^{39}Ar-^{40}Ar$ ages of about 200 Ma (H. Bertrand and G. Feraud, pers. commun., 1991). Rifting terminated in the Central Atlantic domain with crustal separation between Africa and North America around 180–175 Ma (Favre and Stampfli, 1992). In the central Mediterranean Tethys domain, rifting commenced during the Permian and propagated rapidly westward during the Triassic; rift-related magmatism peaked in the area of Morocco and Algeria during the Late Triassic/earliest Jurassic, prior to Mid-Jurassic crustal separation between North Africa and Europe (Ziegler, 1988, 1992a). Within Africa, areas of minor Permo-Triassic rifting include the on-shore Gabon basin (Reyre, 1984) and the Tezzofi trough along the Pan African suture, southwest of the Hoggar, where Permian–Jurassic alkaline syenitic intrusions occur (Lefranc and Guiraud, 1990).

Neocomian-early Aptian rifting episode

A second stage of rifting, initiated at the transition from the Late Jurassic to the Early Cretaceous, affected large areas, including the proto-South and Equatorial Atlantic margins, the West and Central African Rift Systems (WCARS) which extend from Nigeria (Benue trough) to Kenya (Anza trough), and the northern African margin from Tunisia to Egypt (Binks and Fairhead, 1992, this volume; Chang et al., 1992, this volume; Genik, 1992, this volume; Guiraud and Maurin, 1992, this volume). Onset of rifting in the Orange River Basin (Namibian margin), along the Benin margin, in the Upper Benue and in the Muglad Basin (western Sudan) appears to be more or less synchronous. However, along the Atlantic Margin and in the WCARS development of some rifted basins may have begun somewhat later (e.g. during the Hauterivian in northern Cameroon). In some instances (e.g. Congo–Gabon margin) two stages of rifting are recognized during the Early Cretaceous. These Early Cretaceous rifting events are probably related to progressive northward propagation of crustal separation between Africa and South America and seafloor spreading in the South Atlantic, including the break down of the Walvis–Sao Paulo Ridge barrier. The end of this rifting stage is marked in the South Atlantic by a very early Aptian strong phase of magmatic activity which affected the Namibia–Angolan and Brazilian sectors of the South Atlantic margins. Eruption of tholeiitic Parana (Brazil) and Etendeka (Namibia) flood basalts has been related to activity of a deep mantle hot spot beneath the newly developing plate boundary (O'Connor and Duncan, 1990).

Magmatism also occurred along the Brazilian Equatorial Atlantic margin and in northern Cameroon, as evident by the emplacement of high level intrusives, ranging in composition from alkaline to tholeiitic basalts and their differentiates (Wilson and Guiraud, 1992, this volume). Initiation of this phase of magmatic activity may be linked to the development of the St. Helena hot spot (O'Connor and Duncan, 1990).

Rift geometries and structural data indicate that starting from the Neocomian onward three or possibly four internally rigid continental 'blocks' began to separate within the African plate, namely the Western, the Austral and the Arabian–Nubian blocks (Guiraud and Maurin, 1992, this volume), with the latter possibly subdivided into a Central and Eastern block (Genik, 1992, this volume). The boundaries of each of these blocks correspond to zones of crustal weakness (e.g. mylonite zones) which were inherited from the Pan-African orogeny. Guiraud and Maurin (1992, this volume) favour a northward movement of the Arabian–Nubian block with respect to the Western and the Austral blocks, whereas Genik (1992, this volume) and Binks and Fairhead (1992, this volume) favour a more northeasterly movement of the Arabian-Nubian block. Binks and Fairhead (1992, this volume) suggest that the Central and South Atlantic rifts developed independently of each other during this early stage of rifting and seafloor spreading and that they coalesced only later into one rift system. Differential movements between North and South America and Africa were taken up by shearing in the area of the Equatorial fracture zone, the Caribbean and within Africa. Definition of an accurate location for the early opening pole of the South Atlantic has proved to be difficult. A better resolution of the fracture zones close to the continental margins by new seismic reflection, aeromagnetic and gravity data, will be shortly available and will provide further constraints on the position of this stage pole.

Aptian–Albian rifting episode

At the end of the Early Aptian, a new rifting episode commenced which mainly affected rifts located along the Equatorial Atlantic margin, within the WCARS (from Benue to southern Chad) and in northern Libya, while the Sudanese rifts, the east Niger Ténéré troughs and the Gao trough of eastern Mali also remained active. This rifting phase lasted until Late Albian times. Magmatic activity was concentrated in the southern parts of the Benue Trough and included both alkaline and transitional basalts and their differentiates (Wilson and Guiraud, 1992, this volume).

Structurally, the NW–SE trending rifts evolved in response to an approximate NE–SW crustal extension, while the E–W/ENE–WSW striking elongated pull-apart basins developed in response to dextral (Cameroon to Sudan) and sinistral (Niger Delta to Lake Chad) strike-slip movements. Essentially orthogonal extensional strain in the basins of the Southern Sudan and East Niger was taken up along the dextral Central African and the sinistral Benue fracture zones, respectively, which provided a link to the Gulf of Guinea. Contemporaneous rapid opening of the Equatorial Atlantic Ocean (Mascle et al., 1988), resulted in linking up of the Central and South Atlantic mid-oceanic spreading ridges via the Equatorial fracture zones. Differential rates of seafloor spreading in the Central and South Atlantic provide an explanation for the rejuvenation of crustal weakness zones in Africa and important lateral displacements along them (Fairhead and Binks, 1991).

The Santonian (80–85 Ma) compressive event

The stratigraphic record of many African basins contains an intra-Santonian hiatus, whereby Campanian sediments unconformably overly Coniacian strata or occasionally an older folded series. This hiatus can be related to a regional compressional episode, referred to as 'the Santonian event', which affected much of the WCARS from the Lower Benue to the Chad–Sudan border (Ngangom, 1983; Avbovbo et al., 1986; Benkhelil et al., 1988). This event is associated with folding, conjugate strike-slip faulting, reverse faulting, often generating transpressional flower structures, development of local schistosities (Abakaliki anticlinorium), and inversion of some of the deepest Early to Middle Cretaceous basins (Doseo and Doba basins; Genik, 1992, this volume). At the same time, the large NW–SE trending rifts of eastern Niger, Sudan and northern Libya continued to develop due to extensional faulting. Structural data indicate a general NW–SE shortening direction, accompanied by a dextral movement along the southern Chad strike-slip fault zone.

The Santonian compressional event can also be recognized elsewhere in Africa, for instance in the Mandera trough of western Somalia (strike and structure similar to Benue trough) and particularly along the North African margin (Morocco to the Syrian Arc; Guiraud, 1986). This event is synchronous with a rapid change in the direction of the African plate motion that is well established by kinematic studies of the Atlantic opening (Klitgord and Schouten, 1986; Fairhead and Binks, 1991; Binks and Fairhead, 1992, this volume). This rapid change in the African plate motion entailed the onset of its collisional interaction with the European plate (Olivet et al., 1984; Ziegler, 1988). At the same time, differences in spreading rates between the Central and South Atlantic spreading ridges were taken up in Africa along the broad WSW–ENE striking zone of deformation described in the previous section. This zone extends from the Equatorial Atlantic across Africa, with deformation focused in the rift zones, located along pre-existing zones of lithospheric weakness. Deformation in the WCARS took place between 85 and 80 Ma; the earlier date is derived from syntectonic metamorphism in North Africa and the Western Alps (Guiraud, 1986).

The Santonian compressive event marked a change in the intra-plate stress regime of Africa which led to distinct changes in fault geometries in many of the intracontinental basins (Genik, 1992, this volume).

Cenomanian–early Eocene sag phase of basin deepening

The occurrence of a distinct 'thermal sag stage' (McKenzie, 1978) in the evolution of the West, North and Central African rifted basins, coupled with a Late Cenomanian–Campanian marine transgression, is significant. During this sag phase broad basins, in excess of 150 km wide developed, containing up to 5 km of thick sediments in the Termit Basin of eastern Niger (Genik, 1992, this volume). According to the McKenzie (1978) model of post-rift basin formation, these basins subsided in response to cooling and contraction of the lithosphere and asthenosphere which were thermally disturbed during the earlier rifting process. The isostatic response to such cooling is flexural subsidence of the crust. In such a thermal setting magmatic activity decreases rapidly and then ceases altogether, as evident in the basins of West and Central Africa.

Good examples of thermal sag basins are the Ténéré Basin (Eastern Niger) which contains 4 to 6 km of marine, continental and lacustrine deposits (Genik, 1992, this volume), the Muglad Basin (W Sudan), which comprises a number of N140°E and N–S striking troughs filled with a thick continental and lacustrine series (Schull, 1988; McHargue et al., 1992, this volume), the Anza Basin (Kenya), which overlays Middle Jurassic to Early Cretaceous NW–SE trending troughs (Mbede, 1987), the Northern Libya basins which are superimposed on Cretaceous N140°E to N160°E oriented rifts and contain thick Paleocene and Early Eocene marine series (Chatellier and Slevin, 1988). Additional flexural basins developed in Nigeria, along the western margins of the Benue–Gongola–Bornu fold zone (Anambra and Gombe-Kerri Kerri basins).

Intra-Eocene compressional event

Within most of the basins of the WCARS an intra-Eocene erosional or depositional hiatus is evident. Late Eocene and younger sediments, referred to as 'Continental terminal', rest unconformably on the older series (Guiraud, 1986). These series may be folded, particularly in the vicinity of large fracture zones such as the Guinea–Nubia lineaments (Guiraud et al., 1985) or the west Hoggar Pan-African suture (Bellion and Guiraud, 1988), and also along the northern margin of Africa, from Morocco to Egypt. The shortening direction is N140°E to N160°E. This compressional event is related to a major stage in the collision between the African and European plates, known as the end Lutetian Pyrenean or Pyrenean–Atlasic phase (ca. 40 Ma; Guiraud, 1986). Similar to the Santonian compressional event, the Pyrenean event can also be correlated with a change in Atlantic flow-line geometries, reflecting a change in the opening direction of the Central Atlantic at about 40 Ma (see fig. 9a in Fairhead and Binks, 1991).

Late Eocene–Oligocene rifting episode

Oligocene rifting, well known from East Africa and Western Europe is also evident in the Ténéré, Sudan and Anza basins, where thick Late Eocene–Oligocene lacustrine and fluviatile sequences fill N140°E to N–S oriented troughs (Mbede, 1987; Schull, 1988; Genik, 1992, this volume; McHargue et al., 1992, this volume).

At the same time, a resurgence of magmatic activity can be observed in many areas, including the Central Atlantic margin, the Hoggar, Air and Tibesti massifs, the Cameroon line and East Africa (Wilson and Guiraud, 1992, this volume). In West and Central Africa these areas of renewed volcanic activity are more or less independent of contemporaneous crustal extension. Magmatism is alkaline in composition and the primary magmas appear to have been derived from a basal lithosphere mantle source which may have been metasomatised during earlier, possibly hot spot related magmatic events (Wilson and Guiraud, 1992, this volume).

The synchronism and similar orientation of these different rift systems, as well as the resurgence of magmatic activity within a very large domain, including Central and East Africa, the Red Sea and Western Europe must be emphasized. The geodynamic processes underlying this event, which has also been mentioned by Ziegler (1992a), are still not clear. In the South Ténéré, Muglad and Anza basins, Late Eocene and Oligocene resumption of crustal stretching reflects reactivation of pre-existing rifts under a renewed intra-plate distensive stress regime.

Neogene magmatic activity

Magmatic activity in West, Central and North Africa increased during the Neogene, with volcanic fields concentrated in Pan-African mobile belts. Although volcanic activity is in some instances closely associated with Cretaceous rifts (e.g. Benue Trough), many volcanic fields lay outside rifted Mesozoic basins and far away from the East African Rift system. Uplift of large domal structures around centres of Neogene volcanic activity suggests that these overlie localized mantle upwellings. These domes are associated with only minor Neogene tensional faulting (e.g. Hoggar, Tibesti), though they appear to straddle the intersection of Mesozoic and older fracture zones. The chemical composition of the extruded magmas indicates that they were derived by partial melting from a zone at the base of the continental lithosphere (Wilson and Guiraud, 1992, this volume). Geodynamic processes controlling the Neogene surge in magmatic activity outside the East African rift system are still uncertain. General upwelling of the asthenosphere beneath the African plate has been postulated by Pavoni (1991, 1992) and may be associated with its diapiric rise into zones of previously attenuated lithosphere.

Role of subsidence / uplift during rifting

Geological evidence clearly indicates that the Cretaceous–Cenozoic rifts of West and Central Africa are associated with broad zones of subsidence. During the Cretaceous, these facilitated the penetration of marine transgressions deep into the African continent (Genik, 1992, this volume). In the Benue Trough, sediments can be seen to onlap basement highs flanking the rift zone. In many of the WCARS basins, an earlier 'syn-rift' tectonic subsidence phase can be separated from a later 'post-rift' thermal sag subsidence phase (see Avbovbo et al., 1986). The sag basins are centred over the syn-rift basins but overstep their margins significantly.

Geophysical modelling of the WCARS rift structures, using gravity data (Fairhead, 1986; Fairhead and Okereke, 1987; Fairhead and Green, 1989), constrained by seismic refraction and reflection data (Stuart et al., 1985), provide rough estimates of the amounts of crustal thinning and extension. Results clearly demonstrate that the zone of lower crustal thinning is considerably wider than the zone of upper crustal extensional faulting and that the zone of mantle lithosphere thinning extends over an even broader region. The isostatic response of this model explains the overall subsidence of the rift shoulders during the rifting phase of basin development and the flexural sag of the rifted regions for periods exceeding 50 Ma after termination of crustal extension. Although these observations fit Rowley and Sahagian's (1986) depth-dependent pure-shear model, which represents a modification of McKenzie's (1978) uniform stretching model, extremely well, there is still insufficient data to evaluate the relationship between the amount of upper crustal extension and the degree of lower crustal and lithospheric attenuation that may include—apart from a mechanical—a thermal component as well (Ziegler, 1992b).

Evidence for basin uplift is restricted to the Santonian and intra-Eocene phases of intraplate compressional which affected the rift basins of WCARS. The massive post-Cretaceous uplift of broad basement swells (e.g. Adamawa, Darfur, Tibesti, Hoggar and Air), which are associated with Cenozoic volcanic fields, may be related to geodynamic processes affecting the sub-lithospheric mantle of Africa; these processes are not yet fully understood. Much of these uplifts may be an isostatic response of the crust to the emplacement of mantle-derived magmas at its base (Wilson and Guiraud, 1992, this volume).

Conclusions

During the break up of Pangea and Gondwana, a sequence of more or less discrete rifting cycles affected Africa, commencing with the Permo-Carboniferous development of the Karoo rifts, the Permo-Triassic Tethys rifts, the Mid-Triassic Central Atlantic rift system and the Early Cretaceous South Atlantic rift system.

The Early Cretaceous rifting episodes of Africa show strong spatial and temporal links with the opening of the South and Equatorial Atlantic Ocean. In contrast, end Cretaceous–Early Cenozoic rift episodes of Africa, which post-date crustal separation between South America and Africa, reflect the development of a new extensional stress regime that probably developed in response to differences in the rates of seafloor spreading in the Central and South Atlantic oceans.

Evolution of the West and Central African rift system was accompanied by a generally low level of magmatic activity. An exception is the Early Cretaceous magmatism of the Benue Trough; the latter evolved in conjunction with the opening of the Gulf of Guinea. However, there is considerable Mesozoic and Cenozoic magmatic activity outside the rifted basins of Africa.

The Early Cretaceous rifting phases of the South Atlantic and African domains, as well as the compressional Santonian and intra-Eocene events and the Late Eocene–Oligocene rifting phase of Africa can all be correlated with changes in 'flowline' geometry in the Central Atlantic. Changes in the rates of seafloor spreading can be related to changes in plate interactions.

Geophysical studies of the crustal and lithospheric structure of the West and Central African rifted basins indicate that these subsided in response to large amounts of crustal extension. The individual rifts are linked to oceanic domains via major strike-slip fault zones. The rifted basins of Africa provided weak zones in an otherwise stable craton and are extremely sensitive to changes in the regional stress regime (inversion, tensional reactivation).

The depth-dependent, pure-shear lithospheric stretching model of Rowley and Sahagian (1986) appears to account for most of the observations in the West and Central African rift system. However, during the initial stages of rifting, activity of a deep mantle hot spot (St. Helena) in the Equatorial region presumably played a major role in weakening the continental lithosphere by initiating its partial melting.

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