Paleoposition and Paleogeography of Egypt During the Phanerozoic Era

Uwe Kirscher, Edoardo Dallanave, and Valerian Bachtadse

Abstract

The paleogeographic position of Egypt through the Phanerozoic is tightly connected to the motion of the African continent. Paleogeographic studies using paleomagnetism of rock samples from Egypt range back to the 70s and 90s of the last century, but they also continued until very recent times. Paleomagnetic data generally confirm that Egypt was part of Africa in the last ~150–200 Ma. Before that, high-quality paleomagnetic data from Egypt are sparse and possibly affected by remagnetization. Using the master apparent polar wander path of Africa and continental reconstructions, we reviewed the paleoposition of Egypt throughout the Phanerozoic. The general trend is a location of Egypt near the paleo-South Pole during the early Paleozoic, followed by a northward motion accompanied by rotational movements.

Keywords

Egypt • Paleogeography • Paleomagnetism • Gondwana

U. Kirscher (✉)
Department of Geosciences, Eberhard Karls University of Tübingen, Tübingen, Germany
e-mail: uwe.kirscher@uni-tuebingen.de

Earth Dynamics Research Group, The Institute for Geoscience Research (TIGeR), School of Earth and Planetary Sciences, Curtin University, WA 6102 Bentley, Australia

E. Dallanave
Faculty of Geosciences, University of Bremen, Bremen, Germany

V. Bachtadse
Department of Geo- and Environmental Sciences, Ludwig- Maximilians University, Munich, Germany

1 Introduction of Paleomagnetic Work in Egypt

Paleomagnetic work in Egypt started in the 1970s involving scientists mostly from Egypt, Germany, and the Czech Republic (El Shazly & Krs, 1971, 1973; Saradeth et al., 1987; Schult et al., 1978, 1982). Most paleomagnetic studies were related to paleogeography trying to establish the paleoposition of Egypt during the Cenozoic and the Mesozoic. The second major focus is related to Cenozoic magmatism (e.g., Ressetar et al., 1981). Paleomagnetic poles determined from these early studies indicate that Egypt did not go through major movement between ~200 and 100 Ma and roughly place the position of Egypt near the paleo-equator (El Shazly & Krs, 1973). A more recent collaboration between scientists from the USA and Belgium resulted in paleomagnetic data from Paleocene–Eocene sediments indicating pervasive remagnetization overprinting the primary magnetic signal (Kent & Dupuis, 2003). Other studies including a publication on Neoproterozoic dikes confirm the presence of widespread remagnetization affecting various rock formations in Egypt (Saleh, 2020). Other studies reveal primary magnetic signals, which show a counterclockwise rotation of Egypt between the Cretaceous and the present day (Lotfy, 2015). Recently, Perrin and Saleh (2018) obtained new high-quality data and also presented a review of Cretaceous to Cenozoic paleomagnetic data including calculation of an apparent polar wander path (APWP) for Egypt. They pointed out some discrepancy between the Egyptian data compared with the master APWP from Africa and proposed different explanations for this: (1) inclination flattening of paleomagnetic directions, (2) age uncertainties, or (3) remagnetization. We present a review of the paleomagnetic data of Egypt for the entire Phanerozoic and the corresponding paleogeographic position for Egypt during that time. We furthermore present a mean APWP calculated using the Egyptian data and a comparison with African and Gondwanan data compilations.

Z. Hamimi et al. (eds.), *The Phanerozoic Geology and Natural Resources of Egypt*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-95637-0_4

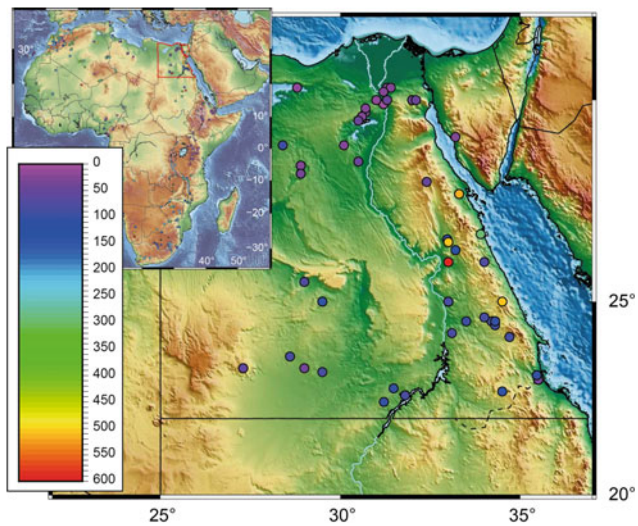

Fig. 1 Topographic map of Africa (small) and Egypt (large) including locations of paleomagnetic studies color coded by age. Ages of color bar are in Ma. Maps generated using Generic Mapping Tools (Wessel & Luis, 2017) and topographic dataset ETOPO1 (Amante & Eakins, 2009)

2 Material and Methods

To assess the paleoposition of Egypt throughout the Phanerozoic, we took a rather straightforward approach. First, we present a compilation of available paleomagnetic data for the entire Phanerozoic (Fig. 1) without considering potential remagnetization. Subsequently, a mean APWP was calculated adopting 50 Ma windows, eventually compared to the global synthetic APWP (GAPWP) of Torsvik et al. (2012). This includes global entries classified by using the quality criteria of Van der Voo (1990) and rotated into African coordinates by using the relative fits listed in Torsvik et al. (2008). To account for the Benue rift (Benkhelil, 1989), paleomagnetic data older than ~ 200 Ma were rotated into a West African and subsequently South African reference frame using rotation parameters of Kidane et al. (2013) and Torsvik et al. (2012). After that, a continental paleogeographic model was used to obtain paleogeographic maps for the entire Phanerozoic (Torsvik et al., 2014). To reconstruct the continents of the world including northern Africa, we used the software GPlates (Müller et al., 2018)

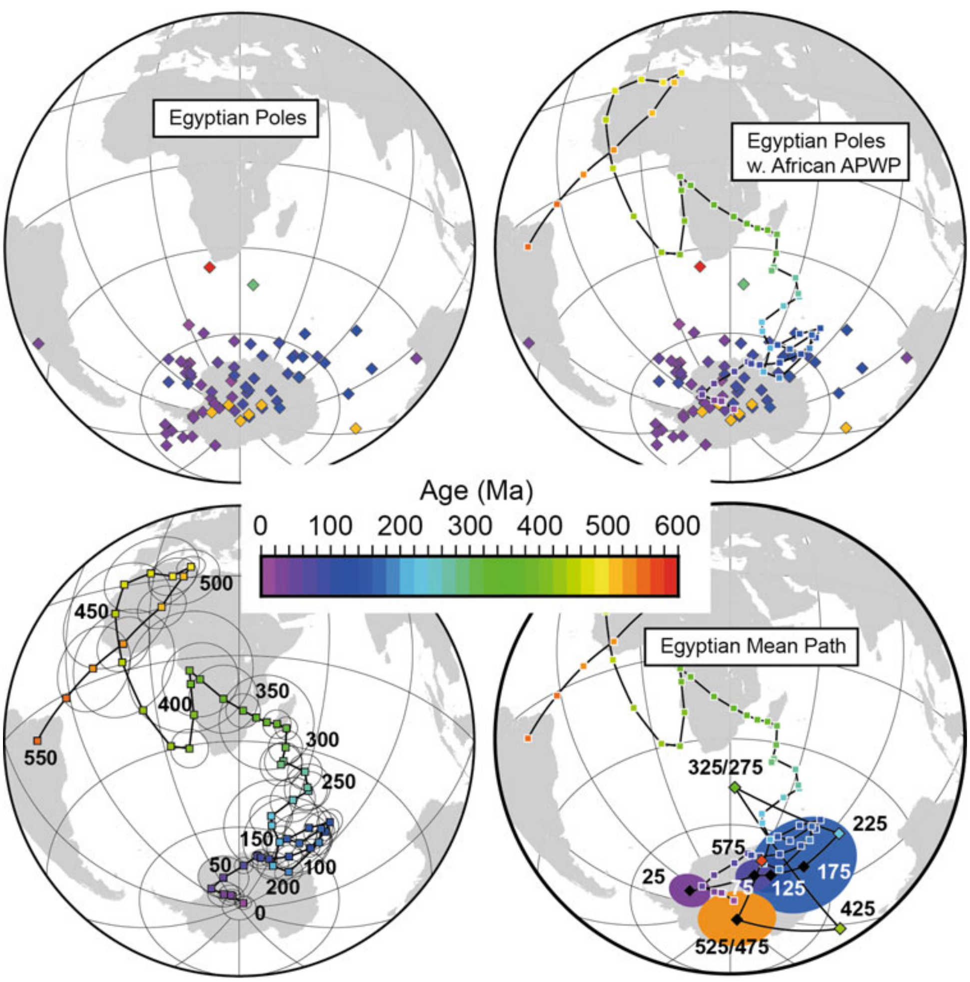

Fig. 2 Paleomagnetic data of Egypt (top left) color coded by age. Top right: Egyptian data together with the master APWP of Africa (Torsvik et al., 2012). Bottom left: master APWP with according error intervals. Bottom right: mean APWP of Egyptian data together with master APWP of Africa. Egyptian data were rotated into a South African reference frame using rotation parameter of Torsvik et al., (2012) for ages younger than 200 Ma and older than 50 Ma. Mean data older than 200 Ma were rotated first into a West African reference frame accounting for the Benue rift and subsequently into a South African frame using parameters of Kidane et al. (2013) and Torsvik et al. (2012). Mean path is labeled with median age (e.g., 75 represents 50–100 Ma interval)

and the Generic Mapping Tools (Wessel & Luis, 2017). For the topographic data, we used the ETOPO1 dataset of Amante and Eakins (2009).

3 Results

As expected from previous studies (e.g., Perrin & Saleh, 2018), the general trend of the GAPWP is also visible in the Egyptian APWP (Fig. 2). In present coordinates, the Egyptian APWP between 25 and 225 Ma moves from Antarctica toward Australia. This supports the proposed counterclockwise rotation of the African continent between the early Cretaceous and the present day (Lotfy, 2015). Prior to the 200–250 Ma window, the data get extremely sparse, but all poles lie within $\sim 50°$ from the present-day South Pole. This is likely the consequence of remagnetization of all older rocks related to Mesozoic or Cenozoic magmatism (Saleh, 2020). This is particularly evident for the 450–500 Ma and 500–550 Ma intervals, which plot very close to the South Pole and in proximity of the 0–50 Ma and 50–100 Ma poles.

4 Paleogeographic Evolution

To illustrate the paleogeographic evolution, we present reconstruction snapshots every 50 Ma (except for the 35 Ma reconstruction; Figs. 3, 4, and 5) based on a deep-mantle-structure reference frame (Torsvik & Cocks, 2016; Torsvik et al., 2014). Figure 3 shows snapshots of 250, 200, 150, 100, 35 Ma, and present day (0 Ma).

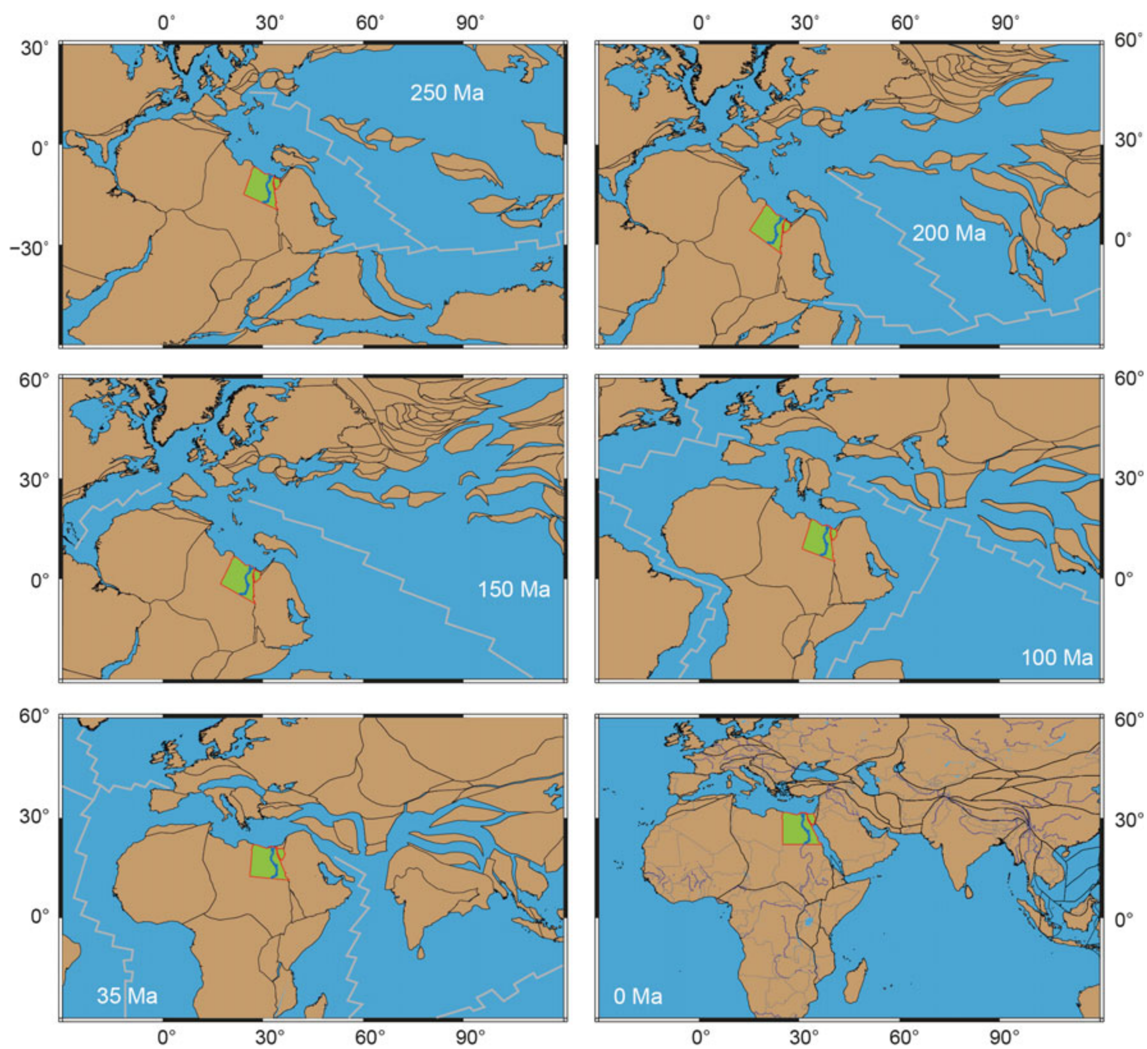

Fig. 3 Paleogeographic reconstructions for distinct time slices based on continental models of (Torsvik et al., 2014). Reconstructions were made using GPlates (Müller et al., 2018) and GMT (Wessel & Luis, 2017). Egypt is highlighted with red contour and green fill color. Reconstructed mid-ocean ridges are indicated based on Stampfli and Borel (2002)

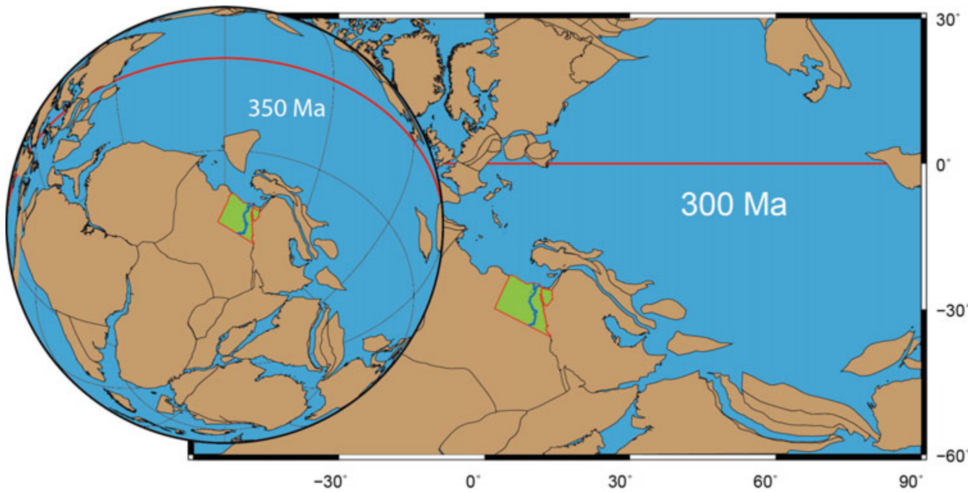

Fig. 4 Paleogeographic reconstructions similar as in Fig. 3 for 300 and 350 Ma. Red line shows paleo-equator

Fig. 5 Paleogeographic reconstructions for 400–540 Ma similar as in Fig. 3. Red line shows paleo-equator

4.1 Mesozoic–Present

Between 250 and 200 Ma, the main paleogeographic feature is a northward movement of Gondwana, which starts at ~ 220 Ma and ceases at about 190 Ma (Le Pichon et al., 2021). A minor southward movement follows, which puts Egypt close to the paleo-equator at ~ 160 Ma (Fig. 3). Between ~ 160 and 100 Ma, a counterclockwise rotation took place, which stopped roughly at the same time when the Central Atlantic started to open around 100 Ma (Granot & Dyment, 2015). After that, the paleogeographic position of Egypt is modulated by the closure of the Neotethys and the evolution of the Mediterranean (e.g., Stampfli & Borel, 2002, Fig. 3). The slow counterclockwise rotation accompanying the closure of the Neotethys brought Egypt from equatorial positions toward its present-day latitude of ~ 30°N.

4.2 Paleozoic

The Paleozoic evolution (Figs. 4 and 5) of Egypt, which is not supported by primary paleomagnetic data from Egypt itself, is characterized by the peculiar paleogeographic evolution of Gondwana (Evans, 2003; Kirschvink, 1978; Wu et al., 2021a). Gondwana underwent several periods of counterclockwise and clockwise rotations during the whole Paleozoic. Between the beginning of the Phanerozoic at 541 and ~ 500 Ma, Gondwana rotates counterclockwise, which translates Egypt from a position slightly south of the paleo-equator toward ~ 30°S (Fig. 5). Subsequently, Gondwana went through a prolonged, stepwise period of clockwise rotation until ~ 360 Ma with a rotation pole that brings Egypt as far south as 60° at ~ 400 Ma. This was also the time when the formation of Pangea initiated via orthogonal convergence of Laurussia and Gondwana (Wu et al., 2021b). This evolution brought Egypt again toward the paleo-equator at the end of the Paleozoic (Fig. 4).

5 Paleolatitudinal Evolution

To investigate the latitudinal evolution of Egypt through the Phanerozoic, the paleopoles of Africa calculated from the GAPWP (Torsvik et al., 2012), single-locality poles from Egypt (this study) and the derived mean poles of Egypt (this study) were transferred into paleolatitudes using a reference location in the center of Egypt (Lat = 27° and Long = 30°; Fig. 6). The resulting graphs indicate again a good agreement of the Egyptian data with the expected values based on the Africa APWP between 250 Ma and the present (Fig. 6). Additionally, the 250–300 Ma interval matches well with the expected values, whereas between 400 and 550 Ma, remagnetization is most likely. Missing paleolatitude evolution details between 100 and 150 Ma might be related to insufficient number of studies (Fig. 6). Individual results based on Cambrian rocks (Table 1, Fig. 6) might reflect primary signals or at least remagnetization prior to 100 Ma, but more data are needed to verify this.

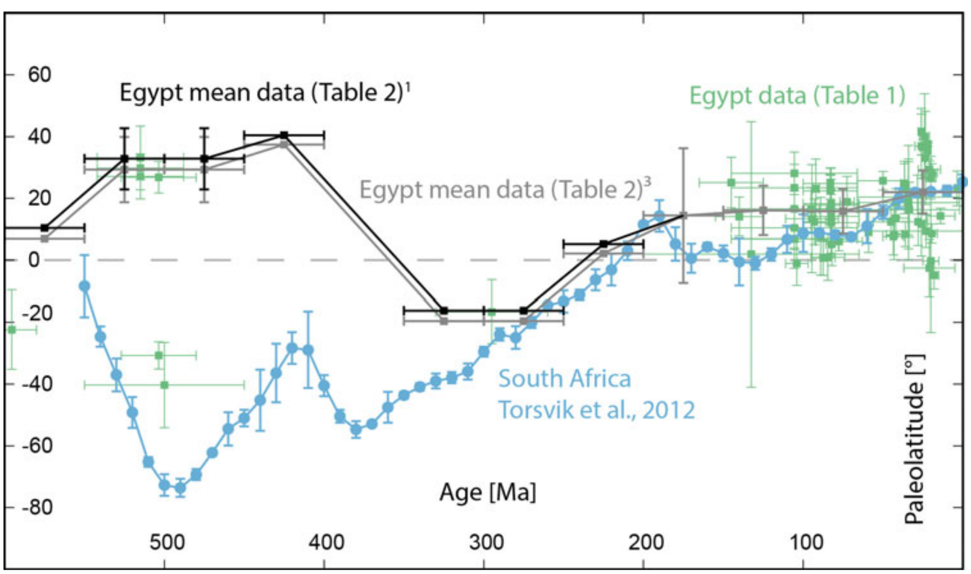

Fig. 6 Paleolatitude versus age plot for Egyptian raw and mean data. All paleolatitude data are calculated for a site of Lat = 27° and Long = 30° within Egypt. Green data represent paleolatitudes for Egyptian raw data (Table 1). Blue curve represents data based on the APWP of Gondwana in South African coordinates (Torsvik et al., 2012). Gray and black data represent the mean data of the Egyptian paleomagnetic dataset. Black data points refer to data rotated into South African coordinates, whereas gray indicates the additional rotation related to the Benue rift (see also Table 2)

Table 1 Paleomagnetic data for Egypt. **Caption**: age: median age estimate; Unc: age uncertainty; Slat and Slong: site coordinates with latitude and longitude; Plat and Plong: paleopole position with respective A_{95}; paleolatitude (λ) and corresponding α_{95} based on a site within Egypt (Lat = 27°, Lat = 30°); Ref: respective reference

Age	Unc	Slat	Slong	Plat	Plong	A_{95}	λ	α_{95}	Reference
3.5	1.5	29.9	31.2	81.4	144.7	5.3	23.2	5.6	Abdeldayem (1999)
14.0	9.0	30.3	28.8	77.0	198.0	2	14.3	2.5	Abdeldayem (1996)
18.0	3.0	28.4	28.9	54.0	180.0	3.2	– 4.9	4.5	Perrin and Saleh (2018)
19.5	3.5	30.0	31.0	66.0	167.0	2.3	8.6	3.1	Lotfy et al., (1995)
19.5	3.5	30.0	31.0	76.0	111.0	3.0	28.3	2.9	Lotfy et al., (1995)
20.0	5.0	28.2	28.9	62.6	206.0	16.3	– 0.3	23	Schult et al., (1982)
20.0	3.0	30.0	32.0	79.0	119.0	7	26.7	6.9	Perrin and Saleh (2018)
21.0	16.0	28.4	28.9	58.2	186.7	6.6	– 2.6	9.3	Hussain et al., (1979)
21.0	7.0	30.0	32.0	76.0	107.0	3	29.3	2.8	Perrin and Saleh (2018)
22.0	0.0	30.3	31.3	68.0	92.0	3	35.3	2.5	Perrin and Saleh (2018)
22.0	0.0	30.3	31.4	70.0	83.0	1	37.6	0.8	Perrin et al., (2009)
23.0	43.0	30.0	32.0	66.0	164.0	4	9.4	5.3	Perrin and Saleh (2018)
23.5	0.5	29.6	30.6	66.9	98.5	17.2	33.1	15.1	Abdeldayem (1999)
24.0	3.0	29.1	33.2	75.0	57.2	17.9	40.1	13.8	Wassif (1991)
25.0	2.0	29.7	30.7	66.0	90.0	3	36.6	2.5	Perrin et al., (2009)
26.0	4.0	29.8	30.7	72.7	81.0	12.7	36.9	10.4	Schult et al., (1982)
26.0	2.0	30.2	31.2	63.5	79.6	10.0	41.6	7.5	El Shazly and Krs (1971)
26.0	2.0	28.5	30.5	68.0	161.0	8	11.7	10.4	Perrin and Saleh (2018)
28.0	6.0	28.9	30.1	68.0	158.0	6	12.4	7.7	Lotfy and Van der Voo (2007)
28.5	5.5	29.6	30.6	79.6	152.2	5.7	21.2	6.3	Abdeldayem (1999)
33.5	31.5	23.3	29.0	74.1	159.8	7.4	16.3	8.9	Hussain and Aziz (1983)
34.0	32.0	23.0	35.5	83.0	190.0	11	20.4	12.3	Niazi and Mostafa (2002)
34.0	32.0	23.0	35.5	50.0	22.0	10	66.2	5.5	Niazi and Mostafa (2002)
34.0	32.0	23.0	35.5	34.0	305.0	16	18.6	18.5	Niazi and Mostafa (2002)
34.0	2.0	23.0	35.5	25.0	112.0	12	17.7	14.1	Niazi and Mostafa (2002)
36.0	2.0	30.0	32.0	64.0	162.0	3	8.4	4.0	Perrin and Saleh (2018)
36.5	2.5	28.2	28.9	83.5	138.6	7.0	24.8	7.2	Schult et al., (1982)
36.5	2.5	28.2	28.9	81.5	145.2	7.6	23.1	8.1	Schult et al., (1978)
42.0	8.0	30.0	31.3	78.1	162.8	3.9	18.6	4.5	Abdeldayem (1999)
42.0	8.0	29.5	30.5	70.0	159.0	4	13.6	5.0	Lotfy and Van der Voo (2007)
43.0	5.0	28.5	30.5	61.0	156.0	6	8.2	8.1	Perrin and Saleh (2018)
43.5	6.5	30.0	32.1	69.4	189.4	4.4	7.6	6.0	Hussain et al., (1979)
45.0	11.0	28.0	32.4	69.0	161.0	3.5	12.4	4.5	Perrin and Saleh (2018)
50.0	16.0	26.0	33.0	88.0	159.0	3	25.7	3.0	Kent and Dupuis (2003)
59.0	2.0	23.3	27.3	72.0	204.0	5	9.1	6.7	Lotfy (2015)
72.5	4.5	25.5	29.0	81.5	225.0	7.2	18.8	8.3	Saradeth et al., (1987)
77.5	14.5	26.0	34.0	63.0	252.3	2.2	6.0	3.0	Ressetar et al., (1981)
82.0	4.0	24.5	34.3	67.0	229.0	5	5.1	6.9	Lotfy (2011)
82.5	17.5	23.6	28.6	77.2	259.0	9.8	18.3	11.4	Hussain and Aziz (1983)
82.5	17.5	23.2	29.5	67.8	268.8	9.6	14.2	12.0	Hussain and Aziz (1983)
82.5	17.5	25.0	33.0	80.4	227.0	4.1	17.8	4.8	Schult et al., (1978)
82.5	17.5	25.0	33.0	79.3	220.0	4.0	16.5	4.8	Schult et al., (1978)
82.5	17.5	24.2	33.1	75.0	203.2	8.3	12.1	10.7	El Shazly and Krs (1973)
83.0	17.0	25.0	29.5	66.0	141.0	9	16.6	10.8	El-Shayeb et al., (2013)

(continued)

Table 1 (continued)

Age	Unc	Slat	Slong	Plat	Plong	A_{95}	λ	α_{95}	Reference
83.0	17.0	22.6	31.8	83.0	283.0	5	24.8	5.1	Mostafa et al., (2016)
83.0	17.0	22.6	31.8	78.0	280.0	5	22.4	5.4	Mostafa et al., (2016)
84.5	10.5	24.1	34.7	61.1	237.6	5.3	0.9	7.5	Ressetar et al., (1981)
87.5	7.5	24.5	34.2	63.5	217.9	4.0	0.7	5.7	El Shazly and Krs (1973)
89.0	2.0	24.6	34.0	59.1	266.0	9.3	7.7	12.6	Ressetar et al., (1981)
92.0	2.0	24.5	34.3	86.0	223.0	9	23.1	9.6	Lotfy (2011)
93.0	7.0	24.4	34.3	69.3	258.1	5.8	12.4	7.4	Schult et al., (1982)
94.5	16.5	24.5	33.5	75.7	228.3	13.8	13.4	17.5	Ressetar et al., (1981)
95.0	5.0	28.9	28.4	71.0	151.0	6	16.3	7.2	Odah (2004)
104.0	7.0	24.5	34.3	55.0	250.0	5	– 1.1	7.1	Lotfy (2011)
105.5	39.5	23.12	35.46	59.0	273.0	4.9	10.4	6.5	Perrin and Saleh (2018)
105.5	39.5	23.12	35.46	57.0	302.0	7.2	23.4	7.6	Perrin and Saleh (2018)
105.5	39.5	22.78	31.48	64.0	252.0	2.5	6.8	3.4	Perrin and Saleh (2018)
105.5	39.5	22.43	31.21	62.0	258.0	7.0	6.9	9.6	Perrin and Saleh (2018)
105.5	39.5	26.57	32.97	87.0	323.0	7.2	28.1	6.9	Perrin and Saleh (2018)
105.5	39.5	26.57	32.97	48.0	295.0	4.9	16.6	5.9	Perrin and Saleh (2018)
132.5	67.5	26.3	33.2	44.9	273.0	30.4	1.9	42.9	Hussain et al., (1979)
140.0	15.0	22.7	34.5	68.0	268.0	5	14.1	6.3	Abd El-All (2004)
145.0	20.0	25.0	29.5	78.0	294.0	8	25.1	8.2	El-Shayeb et al., (2013)
295.0[3]	35.0	26.7	33.9	42.7	216.2	8.6	– 16.6	10.3	Nairn et al., (1987)
500.0[3]	50.0	26.0	33.0	– 53.5	147.0	18.0	– 40.3	13.8	Davies et al., (1980)
503.5[3]	23.5	26.5	33.0	– 87.3	124.2	4.8	– 30.7	4.4	Davies et al., (1980)
503.5[3]	23.5	25.0	34.5	85.1	165.7	5.2	26.8	5.1	Davies et al., (1980)
515.0[3]	27.0	27.7	33.3	87.3	25.9	11.8	33.1	10.3	Abdullah et al., (1984)
515.0[3]	27.0	27.7	33.3	81.6	120.8	4.1	29.8	3.8	Abdullah et al., (1984)
515.0[3]	27.0	27.7	33.3	82.7	273.5	7.4	27.1	7.3	Abdullah et al., (1984)
595.5[3]	15.5	26.0	33.0	36.1	197.1	11.9	– 22.4	12.8	Davies et al., (1980)

Table 2 Paleomagnetic mean data for Egypt. **Caption**: Age: median age bin for paleomagnetic mean data; Long/Lat: longitude and latitude of mean paleopole for respective age bin with according paleolatitude (λ) and α_{95} based on a site within Egypt (Lat = 27°, Lat = 30°); mean paleopoles are based on paleomagnetic data from Egypt in the same Northeast African (NEA) reference frame and rotated into South African (SA using rotation parameter of Lat = 40.5°, Long = – 61.4°, angle = – 0.7°, Torsvik et al., 2012), West African (WA, rotation parameters of Lat = 19.2°, Long = 352.6°, angle = – 6.3°, Kidane et al., 2013), and into West and subsequent South African reference frame (WA–SA, rotation parameters of WA, see latter, and to SA of Lat = 33.6°, Long = 26.0°, angle = 2.3°, Torsvik et al., 2012)

	NEA					To SA[1]				To WA[2]		To WA–SA[3]			
Age	Long	Lat	A_{95}	λ	α_{95}	Long	Lat	λ	α_{95}	Long	Lat	Long	Lat	λ	α_{95}
25	139.9	77.0	6.4	22.0	7.0	139.9	77.0	22.0	7.0						
75	244.5	76.5	5.9	15.7	7.2	244.7	76.6	15.8	7.2						
125	260.0	73.3	6.6	15.7	8.0	261.0	73.6	16.1	8.0						
175	274.9	64.0	17.5	14.0	21.9	275.5	64.2	14.4	21.8						
225	273.0	44.9	–	1.9	–	273.0	45.1	2.1	–	272.1	51.0	274.3	49.2	5.2	
275	216.2	42.7	–	20.1	–	215.8	43.2	19.6	–	209.1	46.6	212.4	46.8	– 16.6	
325	216.2	42.7	–	– 20.1	–	215.8	43.2	– 19.6	–	209.1	47.0	212.4	46.8	– 16.6	
425	327.0	53.5	–	37.3	–	327.2	53.2	37.4	–	332.8	55.5	332.5	54.0	40.4	
475	322.3	84.8	11.3	28.9	10.8	327.0	84.6	29.3	10.6	27.6	84.0	11.0	83.8	32.8	9.9
525	322.3	84.8	11.3	28.9	10.8	327.0	84.6	29.3	10.6	27.6	84.0	11.0	83.8	32.8	9.9
575	244.0	65.9	68.1	6.5	93.7	244.2	66.3	6.9	93.3	236.2	71.8	242.2	70.8	10.4	–

6 Summary

In summary, due to the pervasive remagnetization suffered by several rock formations and the absence of primary paleomagnetic data from Paleozoic rocks, the authochtonous Egyptian dataset is not ideal to establish the paleogeographic evolution of Egypt throughout the whole Phanerozoic. However, for the last 150–200 Ma, the available data are in good agreement with each other and also with rotated data from other areas of Africa. Using most recent continental paleogeographic reconstructions, the evolution of Egypt went from a position close to the paleo-equator at the beginning of the Phanerozoic toward ~ 60°S at ~ 400 Ma and back toward ~ 30°N at present day. This evolution is related to rotational movements of Gondwana, the northward motion of Pangea, and the closure of the Neotethys.

Acknowledgements We thank the editors of this book Zakaria Hamimi, Hassan Khozyem, and Haytham El Atfy for giving us the possibility to provide this chapter. We furthermore thank two constructive reviews by Massimo Mattei and Tesfaye Kidane Birke, whose comments led to a significant improvement of the chapter.

References

Abd El-All, E. (2004). Paleomagnetism and rock magnetism of El-Naga ring complex South Eastern Desert, Egypt: NRIAG. *Journal of Geophysics, 3*(1), 1–25.

Abdeldayem, A. (1996). Palaeomagnetism of some Miocene rocks, Qattara depression, Western Desert, Egypt. *Journal of African Earth Sciences, 22*(4), 525–533.

Abdeldayem. (1999). Palaeomagnetism of some Cenozoic sediments. *Cairo-Fayum Area, Egypt: Physics of the Earth and Planetary Interiors, 110*(1–2), 71–82.

Abdullah, A., Nairn, A., Savino, D., & Sprague, K. (1984). Paleomagnetic study of some of the dikes from the Esh El Mellaha Range, Eastern Desert, Egypt. *Journal of African Earth Sciences (1983), 2*(3), 267–275.

Amante, C., & Eakins, B. W. (2009). ETOPO1 Global Relief Model converted to PanMap layer format. *PANGAEA*.

Benkhelil, J. (1989. The origin and evolution of the Cretaceous Benue Trough (Nigeria). *Journal of African Earth Sciences (and the Middle East), 8*(2–4), 251–282.

Davies, J., Nairn, A., & Ressetar, R. (1980). The paleomagnetism of certain late Precambrian and early Paleozoic rocks from the Red Sea Hills. *Eastern Desert, Egypt: Journal of Geophysical Research: Solid Earth, 85*(B7), 3699–3710.

El Shazly, E., & Krs, M. (1973). Paleogeography and paleomagnetism of the Nubian Sandstone eastern desert of Egypt. *Geologische Rundschau, 62*(1), 212–225.

El-Shayeb, H., El-Hemaly, I., Aal, E. A., Saleh, A., Khashaba, A., Odah, H., & Mostafa, R. (2013). Magnetization of three nubia sandstone formations from central western desert of Egypt: NRIAG Journal of. *Astronomy and Geophysics, 2*(1), 77–87.

Evans, D. A. D. (2003). *True Polar Wander and Supercontinents: Tectonophysics, 362*(1–4), 303–320.

Granot, R., & Dyment, J. (2015). The Cretaceous opening of the South Atlantic Ocean. *Earth and Planetary Science Letters, 414*, 156–163.

Hussain, A. G., & Aziz, Y. (1983). Paleomagnetism of Mesozoic and Tertiary rocks from East El Owenat Area, southwest, Egypt. *Journal of Geophysical Research: Solid Earth, 88*(B4), 3523–3529.

Hussain, A. G., Schult, A., & Soffel, H. (1979). Palaeomagnetism of the basalts of Wadi Abu Tereifiya, Mandisha and dioritic dykes of Wadi Abu Shihat, Egypt. *Geophysical Journal International, 56*(1), 55–61.

Kent, D. V., & Dupuis, C. (2003). Paleomagnetic study of the Paleocene-Eocene Tarawan chalk and Esna Shale: dual polarity remagnetizations of Cenozoic sediments in the Nile Valley (Egypt). *Micropaleontology, 49*(Suppl_1), 139–146

Kidane, T., Bachtadse, V., Alene, M., & Kirscher, U. (2013). Palaeomagnetism of Palaeozoic glacial sediments of Northern Ethiopia: A contribution towards African Permian palaeogeography. *Geophysical Journal International, 195*(3), 1551–1565.

Kirschvink, J. L. (1978). The Precambrian-Cambrian boundary problem: Paleomagnetic directions from the Amadeus Basin. *Central Australia: Earth and Planetary Science Letters, 40*, 91–100.

Lotfy, H., & Van der Voo, R. (2007). Tropical northeast Africa in the middle–late Eocene: Paleomagnetism of the marine-mammals sites and basalts in the Fayum province, Egypt. *Journal of African Earth Sciences, 47*(3), 135–152.

Lotfy, H. I. (2011). Active concomitant counterclockwise rotation and northwards translation of Africa during the Albian-Campanian time: A paleomagnetic study on the Wadi Natash alkaline volcanic province (104–78 Ma). *South Eastern Desert, Egypt: Palaeogeography, Palaeoclimatology, Palaeoecology, 310*(3–4), 176–190.

Lotfy, H., Van der Voo, R., Hall, C., Kamel, O., & Aal, A. A. (1995). Palaeomagnetism of Early Miocene basaltic eruptions in the areas east and west of Cairo. *Journal of African Earth Sciences, 21*(3), 407–419.

Lotfy,. (2015). Early Cretaceous counterclockwise rotation of Northeast Africa within the equatorial zone: Paleomagnetic study on Mansouri ring complex. *Southeastern Desert, Egypt: NRIAG Journal of Astronomy and Geophysics, 4*(1), 1–15.

Mostafa, R., Khashaba, A., El-Hemaly, I., Takla, E., Abdel Aal, E., & Odah, H. (2016). 1st paleomagnetic investigation of Nubia Sandstone at Kalabsha, south Western Desert of Egypt. *NRIAG Journal of Astronomy and Geophysics, 5*(1), 254–262

Müller, R. D., Cannon, J., Qin, X. D., Watson, R. J., Gurnis, M., Williams, S., Pfaffelmoser, T., Seton, M., Russell, S. H. J., & Zahirovic, S. (2018). GPlates: Building a virtual earth through deep time. *Geochemistry Geophysics Geosystems, 19*(7), 2243–2261.

Nairn, A., Perry, T., Ressetar, R., & Rogers, S. (1987) A paleomagnetic study of the Dokhan Volcanic formation and younger granites, eastern desert of Egypt. *Journal of African Earth Sciences (1983), 6*(3), 353–365.

Niazi, H., & Mostafa, M. (2002). A paleomagnetic study of the Tertiary basaltic lava flows around Wadi Hudayn Shalatayn area, south Eastern Desert, Egypt. *Annals Geological Survey, Egypt*, 429–442.

Odah, H. (2004). Paleomagnetism of the Upper Cretaceous Bahariya Formation, Bahariya Oasis, Western Desert, Egypt. *Journal of Applied Geophysics, 3*(2), 177–187.

Perrin, M., Saleh, A., & Alva-Valdivia, L. (2009). Cenozoic and Mesozoic basalts from Egypt: A preliminary survey with a view to paleointensity. *Earth, planets and space, 61*(1), 51–60.

Perrin, M., & Saleh, A. (2018). Cenozoic to Cretaceous paleomagnetic dataset from Egypt: New data, review and global analysis. *Earth and Planetary Science Letters, 488*, 92–101.

Le Pichon, X., Jellinek, M., Lenardic, A., Şengör, A. C., & İmren, C. (2021). Pangea Migration. *Tectonics, 40*(6), e2020TC006585.

Ressetar, R., Nairn, A., & Monrad, J. (1981). Two phases of cretaceous—tertiary magmatism in the eastern desert of Egypt: Paleomagnetic, chemical and K-Ar evidence. *Developments in geotectonics* (Vol. 17, pp. 169–193). Elsevier.

Saleh, A. (2020). Paleomagnetism of Late Neoproterozoic African Dike Swarms from the South Eastern Desert and the Paleo-Neoproterozoic dataset from Egypt. *Pure and Applied Geophysics, 177*(11), 5251–5262.

Saradeth, S., Soffel, H., & Schult, A. (1987) Paleomagnetic and rockmagnetic studies in SW-Egypt and N-Sudan: contributions to the African polar wander path.

Schult, A., Soffel, H., & Hussain, A. (1978). Palaeomagnetism of Cretaceous Nubian sandstone, Egypt. *Journal of Geophysics, 44*(4), 333–340

Schult, A., Hussain, A., & Soffel, H. (1982). Palaeomagnetism of Upper Cretaceous volcanics and Nubian sandstones of Wadi Natash. *SE Egypt and Implications for the Polar Wander Path for Africa in the Mesozoic: Journal of Geophysics, 50*(1), 16–22.

El Shazly, E. M., & Krs, M. (1971) Magnetism and palaeomagnetism of Oligocene basalts from Abu Zaabal and Qatrani, northern Egypt. *Geolysi Kalai Sbornik, 19*(356), 261–270

Stampfli, G. M., & Borel, G. (2002). A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons. *Earth and Planetary Science Letters, 196*(1–2), 17–33.

Torsvik, T. H., Muller, R. D., Van der Voo, R., Steinberger, B., & Gaina, C. (2008). Global plate motion frames: Toward a unified model. *Reviews of Geophysics, 46*(3).

Torsvik, T. H., van der Voo, R., Preeden, U., Mac Niocaill, C., Steinberger, B., Doubrovine, P. V., van Hinsbergen, D. J. J., Domeier, M., Gaina, C., Tohver, E., Meert, J. G., McCausland, P. J. A., & Cocks, L. R. M. (2012). Phanerozoic polar wander, palaeogeography and dynamics. *Earth-Science Reviews, 114*, 325–368.

Torsvik, T. H., & Cocks, L. R. M. (2016). *Earth history and palaeogeography*. Cambridge University Press.

Torsvik, T. H., van der Voo, R., Doubrovine, P. V., Burke, K., Steinberger, B., Ashwal, L. D., Trønnes, R. G., Webb, S. J., & Bull, A. L. (2014). Deep mantle structure as a reference frame for movements in and on the Earth. *Proceedings of the National Academy of Sciences, 111*(24), 8735–8740.

Van der Voo, R. (1990). *The Reliability of Paleomagnetic Data: Tectonophysics, 184*(1), 1–9.

Wassif, N. A. (1991). Palaeomagnetism and opaque mineral oxides of some basalt from west central Sinai, Egypt. *Geophysical Journal International*, *104*(2), 319–330.

Wessel, P., & Luis, J. F. (2017). *The GMT/MATLAB Toolbox: Geochemistry Geophysics Geosystems, 18*(2), 811–823.

Wu, L., Huang, W., Liang, H., Brendan Murphy, J., Kirscher, U., Mitchell, R. N., Hawkins, L. M. A., Halverson, G. P., Gu, Y. J., Zhang, J., & Liu, X. (2021a). Paleomagnetism of the Guanyang Devonian sedimentary successions in Guangxi province, South China. *Gondwana Research*.

Wu, L., Murphy, J. B., Quesada, C., Li, Z.-X., Waldron, J. W., Williams, S., Pisarevsky, S., & Collins, W. J. (2021b). The amalgamation of Pangea: Paleomagnetic and geological observations revisited. *Bulletin, 133*(3–4), 625–646.

Uwe Kirscher is a paleomagnetist with a background in geophysics, who received his Ph.D. degree in 2015 from the Ludwig-Maximilians University in Munich (Germany). Thereafter, he spent three years at Curtin University in Australia, after which he worked at Tuebingen University (Germany) between 2019 and 2022. Since early 2023 he is works again at Curtin University in Perth, Australia. His research interests focus on the usage of paleo- and rock magnetic techniques in paleogeography, chronology and Earth's evolution studies. Some of his main fields of interest include human evolution, supercontinent cycles, and paleoclimate studies.

Edoardo Dallanave is a paleomagnetist with a background in stratigraphic geology. He obtained an M. Sc degree from the University of Milan (Italy) in 2004, and a Ph.D. from the University of Padova (Italy) in 2010. From 2012 to 2018, he worked as a research associate at the Ludwig-Maximilians University in Munich (Germany), before moving to the University of Bremen (Germany) where he now works. His research interest is in paleomagnetism and rock-magnetism applied to different chronologic and paleogeographic problems, particularly during the Cenozoic.

Valerian Bachtadse is a geologist/geophysicist who spent the majority of his scientific career applying paleomagnetism to reconstruct the distribution of the continents before, during and after the Hercynian orogeny. After receiving a doctorate degree in 1984 from Johannes-Gutenberg-University, Mainz, Germany, supervised by Alfred Kröner, he moved on to a research professor position at the University of Michigan (USA) where he started working with Rob van der Voo on Paleozoic sediments in South Africa. In 1986, he received a research fellow position at Oxford University where he and Jim Briden were part of a major BP-funded research project studying the paleomagnetism of Paleozoic rocks from eastern and northern Africa. In 1990, he moved on to Ludwig-Maximilians-University in Munich (Germany) where he worked on the Paleozoic of Europe and Central Asia. In addition, he studied the Proterozoic of the Baltic shield, the Permian of southern Europe and northern Africa as well as the Cretaceous/Paleogene boundary and the Quaternary of Armenia and Georgia. In 2020, he retired from his position as a senior research professor.