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SOURCES OF MUMMY BITUMEN IN ANCIENT EGYPT AND PALESTINE*

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Bitumen used as a preservative in ancient Egyptian mummies was previously thought to come only from the Dead Sea in Palestine. Other, closer sources of bitumen were investigated at Abu Durba and Gebel Zeit on the shores of Egypt's Gulf of Suez. Bitumen from these localities and from five mummies was analysed using molecular biomarkers derived from gas chromatography/mass spectrometry. It was found that four of the mummies contained Dead Sea bitumen, and the fifth and oldest (900 BC*) had bitumen from Gebel Zeit, thus providing the first evidence for the use of an indigenous source of bitumen in ancient Egypt.*

KEYWORDS: BITUMEN, MUMMIES, DEAD SEA, PALESTINE, ABU DURBA, GEBEL ZEIT, GULF OF SUEZ, ANCIENT EGYPT, GC/MS, MOLECULAR BIOMARKERS

INTRODUCTION

Petroleum seeping at the Earth's surface inspissates through volatile loss, water washing and biodegradation to form a heavy oil or asphalt. These and other forms of natural hydrocarbons are collectively referred to as bitumen. Bitumen was used in Antiquity as a sealant (for ceramic pots, baskets and boats), an adhesive (for jewellery, tools and masonry), a varnish (for wood, stone and metal), fuel and medicine (Nissenbaum 1978). One of the more renowned uses of bitumen was as a preservative for mummies in ancient Egypt (Bahn 1992). The word 'mummy', in fact, comes from the Persian and later Arabic '*mummiya*', meaning bitumen. Medieval Egyptian tomb robbers noted the black, resinous coating on many corpses and assumed that they had been treated with bitumen. Although bitumen was used in some burials, especially during the Greco-Roman period, the vast majority of the coatings are actually various tree resins (Lucas and Harris 1962, 303–8; Serpico 2000, 454–68).

It is widely assumed that all the bitumen used in ancient Egypt came from the Dead Sea area in Palestine (Fig. 1), where petroleum seeps and asphalt deposits are common (Nissenbaum 1978). Modern gas chromatography/mass spectrometry (GC/MS) analyses indicate that specific terpane and sterane compounds extracted from some archaeological bitumen samples from Egypt are indeed unique to the Dead Sea. These include bitumen from a number of mummies or their wooden coffins, ranging in age from 1500 BC to AD 300 (Zaki and Iskander 1943; Rullkötter and Nissenbaum 1988; Connan 1991; Connan and Dessort 1989, 1991; Nissenbaum 1992), and pieces of asphalt from Maadi dating to the early fourth millennium BC (Connan *et*

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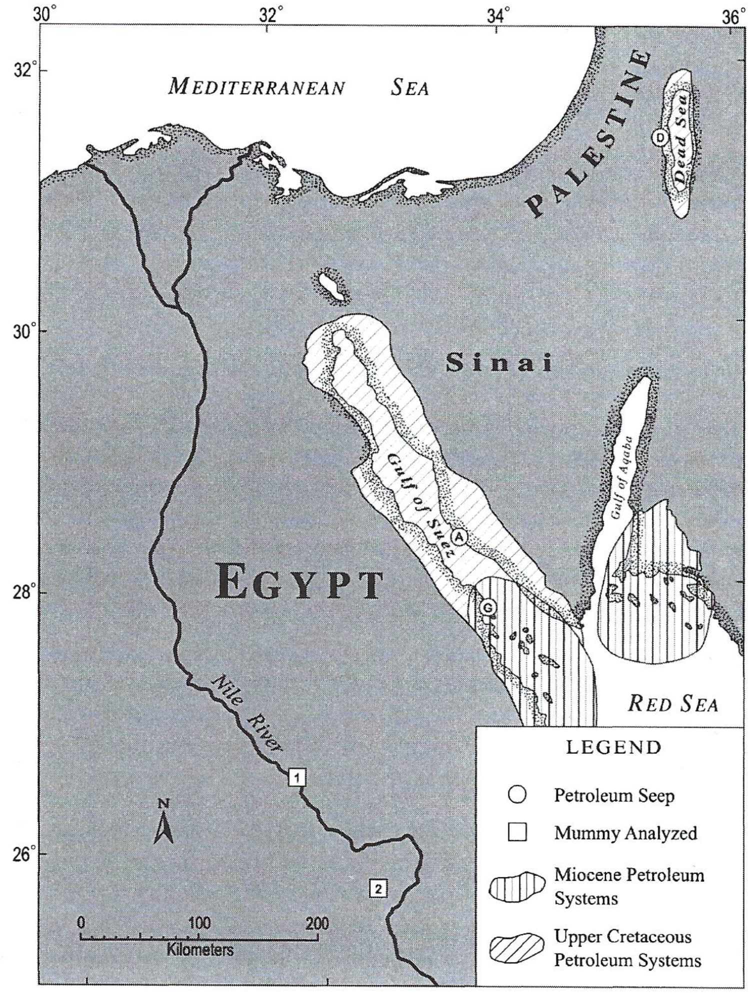

Figure 1 *A map of Egypt and Palestine. Locations include the petroleum systems (Miocene and Upper Cretaceous), the petroleum seeps (D, Dead Sea; A, Abu Durba; G, Gebel Zeit), and find spots of the mummies analysed (1, Akhmin; and 2, western Thebes).*

al. 1992). The view of the Dead Sea as the sole bitumen source is further fostered by the widely perceived absence of bitumen deposits in Egypt, and by two texts from the late first century BC that mention the importation of Dead Sea bitumen into Egypt: Diodorus Siculus' 'Library of History' (section 99 of book 19; for a translation, see Greer 1962, 103), and Strabo's 'Geography' (chapter 2 of book 16; for a translation, see Jones 1966, 297). However, two sites in Egypt with petroleum seeps were not considered in earlier geochemical studies. These sites occur on the shores of the Gulf of Suez at Gebel Zeit, where there are ancient petroleum wells, and at Abu Durba (Fig. 1). At Abu Durba, the seepage is evinced onshore by the presence of asphalt-impregnated sandstone and sulphur-cemented sand, and just offshore by petroleum leakage from the sea floor. At Gebel Zeit, in contrast, active seepage of petroleum occurs on the land surface in an area underlain by asphalt-impregnated limestone. Both seeps are a result of leaky subsurface traps that have been breached by faulting or uplift-induced erosion associated with active rifting in the Gulf of Suez. The availability of these seeps in Antiquity and their closer proximity to Egypt than the Dead Sea makes them prospective sources for the bitumen in Egyptian artefacts.

METHODS

Bitumen samples were collected by the authors from the Dead Sea, Abu Durba and Gebel Zeit seeps. At the latter locality, detailed measurements were made of the ancient wells, and the associated surface pottery was collected and dated. Bitumen samples were also obtained from five mummies ranging in age from the ninth century BC to the second century AD. Four of the mummies are now in the British Museum: Cleopatra, dating to the early second century AD of the Roman period and from western Thebes (BM no. 6706, sample from the wooden coffin); Soter, also dating to the early second century AD of the Roman period and from western Thebes (BM no. 6705, sample from the wooden coffin); Djedoler, dating to *c*. 200 BC of the Ptolemaic period and from Akhmin (BM no. 29776, sample from the body); and Pasenhor, dating to *c*. 900 BC of the Third Intermediate period and from western Thebes (BM no. 24906, sample from the wooden coffin). The bitumen samples from these four mummies were provided by Jurgen Rullkötter (University of Oldenburg, Germany) and Arie Nissenbaum (Weizmann Institute of Science, Israel), and are the same ones as analysed in Rullkötter and Nissenbaum (1988). The fifth mummy, which is now in the Toledo Museum of Art, is that of an unknown priest (TMA no. 1906.1C, sample from the linen wrappings). It dates to *c*. 800 BC of the Third Intermediate period and comes from western Thebes (Knudsen 2001).

Bitumen from both seeps and mummies was analysed by GC/MS, and this allowed identification of the molecular biomarkers or fossils from which definitive correlations can be made between the seeps and mummies. For all bitumen samples, saturate fractions were eluted with *iso*-octane on silica/alumina columns. The analyses were conducted with a Hewlett-Packard 6890 gas chromatograph combined with a JEOL JMS-GCMate magnetic mass spectrometer. The GC used helium as the carrier gas and a Zebron ZB-1 60 m column (0.32 mm ID $\times$ 0.25 μm df, 100% methyl polysiloxane liquid phase).

RESULTS

Abu Durba and Dead Sea bitumen sources

The Abu Durba and Gebel Zeit seeps are fed by different source rocks that represent separate petroleum systems. Both the Abu Durba and Dead Sea seeps derive their petroleum from Late Cretaceous carbonate strata that were buried to sufficient depths in the faulted graben basins of the Dead Sea and Gulf of Suez to mature thermally and generate petroleum (Robison 1994). Diagnostic molecular biomarkers of this source rock, shown in Figure 2, include relatively high concentrations of gammacerane (peak 11) and 17α, 21β(H)-29-pentakishomohopanes (22R and S; peaks 13), and low concentrations of diasteranes (peaks 1–2), 18α(H)-30-neonorhopane (peak 8) and oleanane (peak 9). These relative concentration differences are illustrated in Figure 3 (a) using peak ratio indices in star diagrams. As expected for petroleum generated from the same regional source rock, the star patterns are similar for the Abu Durba and Dead Sea seeps. However, the two basins responsible for generating petroleum in these seeps are separated by more than 300 km (Fig. 1), and the minor but notable differences between Abu Durba and Dead Sea bitumens may reflect variation in the organic facies of the Late Cretaceous strata. Specifically, the lower diasterane and oleanane indices for the Dead Sea bitumen suggest

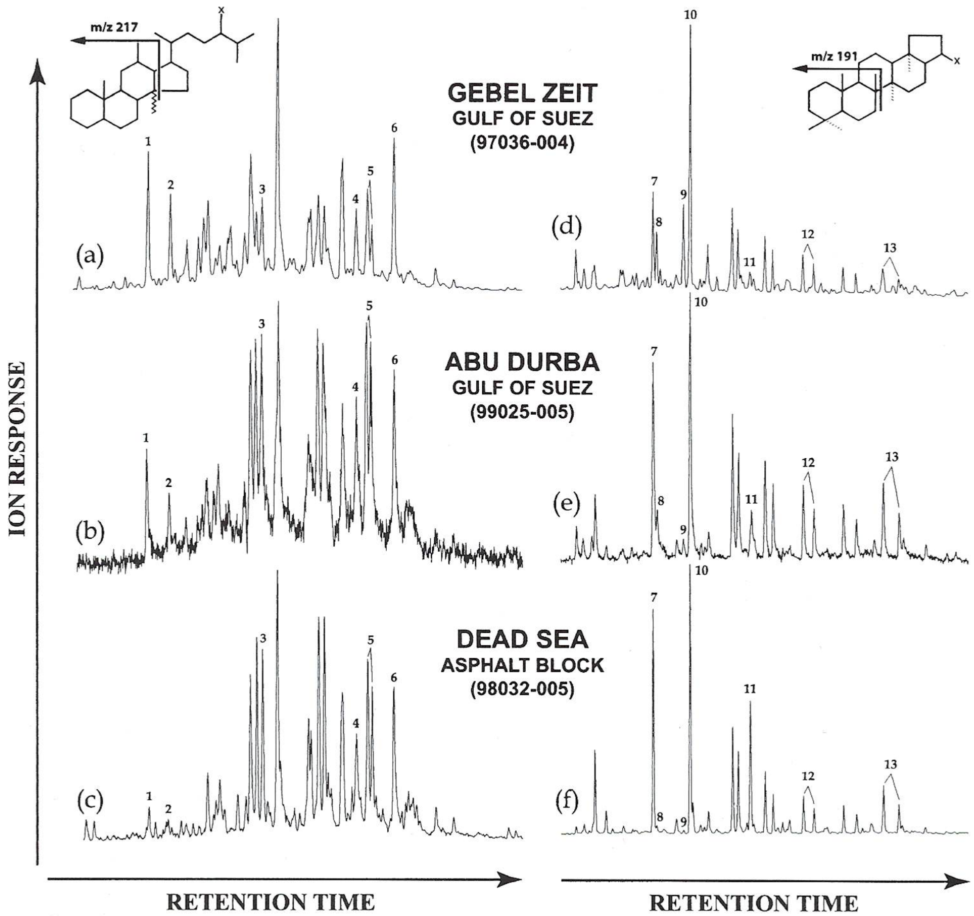

Figure 2 *Petroleum chromatograms. Shown are the m/z 217.196 sterane ion fragments (a–c) and m/z 191.18 pentacyclic terpane ion fragments (d–f) in the saturate fractions of the Gebel Zeit (a, d), Abu Durba (b, e) and Dead Sea (c, f) petroleum seeps. Labelled reference peaks include: (1) 13β, 17α-diacholestane 20S (diasterane); (2) 13β, 17α-diacholestane 20R (diasterane); (3) 5α, 14β, 17β-cholestane 20S; (4) 5α14α17α-stigmastane 20S; (5) 5α, 14β, 17β-stigmastane 20R and 20S; (6) 5α14α17α-stigmastane 20R; (7) 17α, 21β(H)-30-norhopane; (8) 18α(H)-30-neonorhopane; (9) oleanane; (10) 17α, 21β(H)-30-hopane; (11) gammacerane; (12) 17α, 21β(H)-29-trishomohopane 22S and 22R; and (13) 17α, 21β(H)-29-pentakishomohopane 22S and 22R.*

that its organic facies had smaller argillaceous and angiosperm inputs, respectively (Peters and Moldowan 1993, 155–92).

Gebel Zeit bitumen source

The seep at the south end of the Gebel Zeit mountain range has been known to geologists since the early 1800s (de Rozière 1813). The range's Arabic name translates as 'oil' (*zeit*) 'mountain' (*gebel*) and has been in use at least since the mid-1500s, when it appears on the first European maps of the Red Sea (Kamal 1987, 367). Contrary to common claims, there is no evidence that this range was ever called 'Mons Petroleus' by the Romans. Two ancient petroleum wells were first noted at the site of the seep in 1825 (Brocchi 1841, 231–5). Littering the ground around the

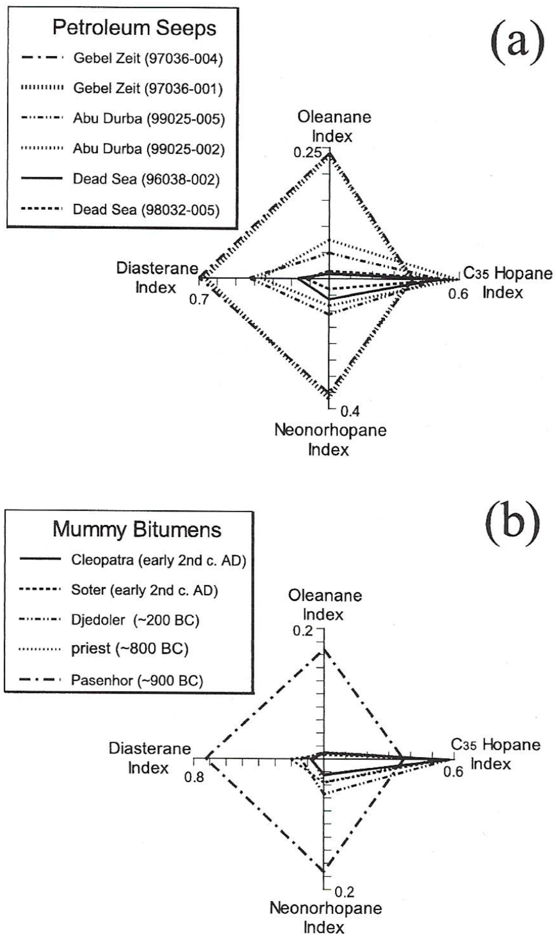

Figure 3 *Petroleum and mummy bitumen star diagrams. Shown are the molecular-fossil indices of (a) petroleum seeps around the Gulf of Suez (Gebel Zeit and Abu Durba) and the Dead Sea (floating asphalt, 98032-005, and Heimar Nukhel seep, 96038-002) and (b) mummy bitumen. Indices are calculated peak heights as decimal fractions: Oleanane Index = oleanane/[oleanane + hopane]; Hopane-C_{35} Index = 17α, 21β(H)-29-pentakishomohopanes/[17α, 21β(H)-29-trishomohopanes + 17α, 21β(H)-29-pentakishomohopanes]; Neonorhopane Index = 18α(H)-30-neonorhopane/[17α, 21β(H)-30-norhopane + 18α(H)-30-neonorhopane]; and Diasterane Index = 13β, 17α-diacholestane 20S/[5α, 14β, 17β-cholestane 20S + 13β, 17α-diacholestane 20S].*

wells are many fragments of ceramic pots, which are the remains of vessels used to transport and store the petroleum. The fragments come mainly from storage jars and amphorae of the early to late Imperial Roman period (first–sixth centuries AD) and the Islamic period (seventh–16th centuries AD), but also present are a few pottery sherds from the Middle Kingdom or Second Intermediate Period (20th–16th centuries BC). Both wells are hand-dug, horizontal tunnels cut through Pleistocene reef limestone (Fig. 4). They are 17 m apart and have open trenches, starting about 15 m inland from the shoreline, leading down to the tunnel entrances. The tunnels are subcircular in cross-section, with diameters varying from 1.5 to 2 m and roofs 1 to 2 m below the ground surface. One tunnel is 6.5 m long and the other one has a length of 3 m; both are oriented approximately perpendicular to the shoreline. The floors of both tunnels

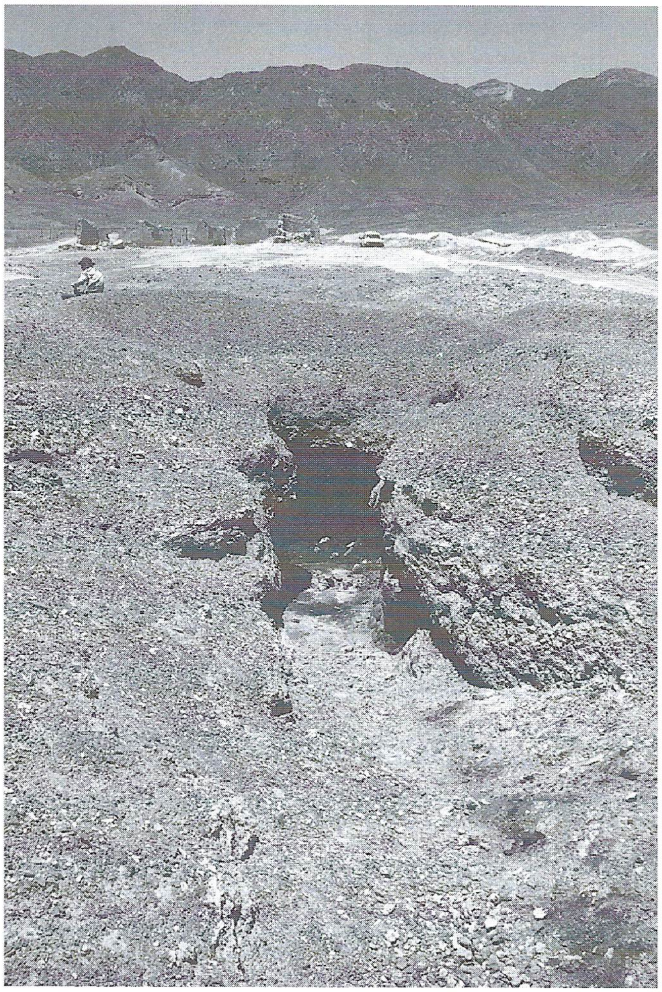

Figure 4 *The northernmost of the two ancient wells at Gebel Zeit. The ruins in the background date from the late 19th century, when petroleum exploration began in the area.*

are cut up to 0.3–0.4 m below current mean sea level, and are covered with a deposit of asphaltic sludge that is overlain by a mixture of petroleum and seawater. The presence of liquid petroleum, through which gas bubbles continually rise, clearly indicates that the seep is still active. Asphalt-impregnated rocks and sediments occur for hundreds of metres around the wells, and this is consistent with a seep that has been flowing since Antiquity.

The Gebel Zeit seep derives its petroleum from Miocene siliciclastic source rocks in the Rudeis, Kareem and Belayim formations (Alsharhan and Salah 1997). Petroleum from these formations is limited to the southern end of the Gulf of Suez and the northern part of the Red Sea (Fig. 1). Sterane and terpane distributions from this petroleum are readily distinguished from those in petroleum derived from the Upper Cretaceous source rock (Fig. 2). Diagnostic molecular fossils of the Miocene source (Figs 2 (a) and (d)) include relatively low concentrations of gammacerane (peak 11) and 17α, 21β(H)-29-pentakishomohopanes (22S and R; peaks 13), and high concentrations of diasteranes (peaks 1–2), 18α(H)-30-neonorhopane (peak 8) and oleanane (peak 9). As can be seen in Figure 3 (a), the star patterns of molecular-fossil indices are strikingly different for the Miocene and Late Cretaceous bitumens.

Mummy bitumen

Figure 5 shows GC/MS traces of the steranes and pentacyclic terpanes extracted from the bitumen of the five mummies. The Cleopatra, Soter, Djedoler and priest mummies have molecular-fossil indices (Fig. 3 (b)) similar to those of the petroleum seeps fed by the Late Cretaceous source rock. The significantly lower oleanane and diasterane indices suggest that the Dead Sea is a more likely source of these bitumens than Abu Durba, despite the latter's closer proximity to Egypt (Fig. 1). This conclusion is consistent with that from a previous analysis of the same British Museum mummies that did not consider the Abu Durba seep (Rullkötter and Nissenbaum 1988).

The bitumen from the fifth and oldest mummy, that of the 'Libyan' Pasenhor, has not previously been correlated with any specific petroleum seep, and was considered unique (Rullkötter and Nissenbaum 1988) with respect to its relatively high concentration of diasteranes and low concentration of gammacerane (Fig. 5 (e)). This mummy bitumen also has relatively low concentrations of 17α, 21β(H)-29-pentakishomohopanes (22S and R), and high concentrations of 18α(H)-30-neonorhopane and oleanane (Fig. 5 (j)). By comparison with Figures 2 (a) and (d), it can be seen that the molecular-fossil indices of the Pasenhor bitumen are similar to those of the Gebel Zeit seep. This correlation indicates that bitumen from Gebel Zeit was used by the Egyptians at least as early as the ninth century BC. It would be surprising if the seep were not already well known long before this time, given that only 16 km north-west of the wells on Gebel Zeit there are extensive galena mines dating from the Middle and New Kingdoms (about 1900–1300 BC; Castel and Soukiassian 1989). That such is, in fact, the case is supported by the presence of pottery sherds at the wells dating to this earlier period.

DISCUSSION AND CONCLUSIONS

Although the Gulf of Suez seeps were much closer to Egypt, it appears that the ancient Egyptians preferred the Dead Sea bitumen. This is perhaps due to its semi-solid nature, which made it more transportable. Also, the Dead Sea area was joined to Egypt by a well-established coastal trading route, whereas bitumen from the Gulf of Suez would have to be brought either across the rugged mountains of the Eastern Desert or up the Gulf of Suez by a circuitous route as long as the direct one from the Dead Sea. It seems, however, that the petroleum from Gebel Zeit would offer some advantages over the semi-solid asphalt of the Dead Sea, both because it would be easier to use in its liquid form and because it has a lower sulphur content (Barakat *et al.* 1997) and, hence, a less foetid smell. In any event, the molecular-fossil indices derived from GC/MS analyses, as used in this study, demonstrate their utility in recognizing petroleum systems and evaluating specific seep locations from which bitumen-bearing artefacts were derived. This methodology needs to be applied to other artefacts from ancient Egypt in order to reveal further details in the bitumen trade with Palestine and the extent of bitumen importation from the Gulf of Suez, and especially from Gebel Zeit.

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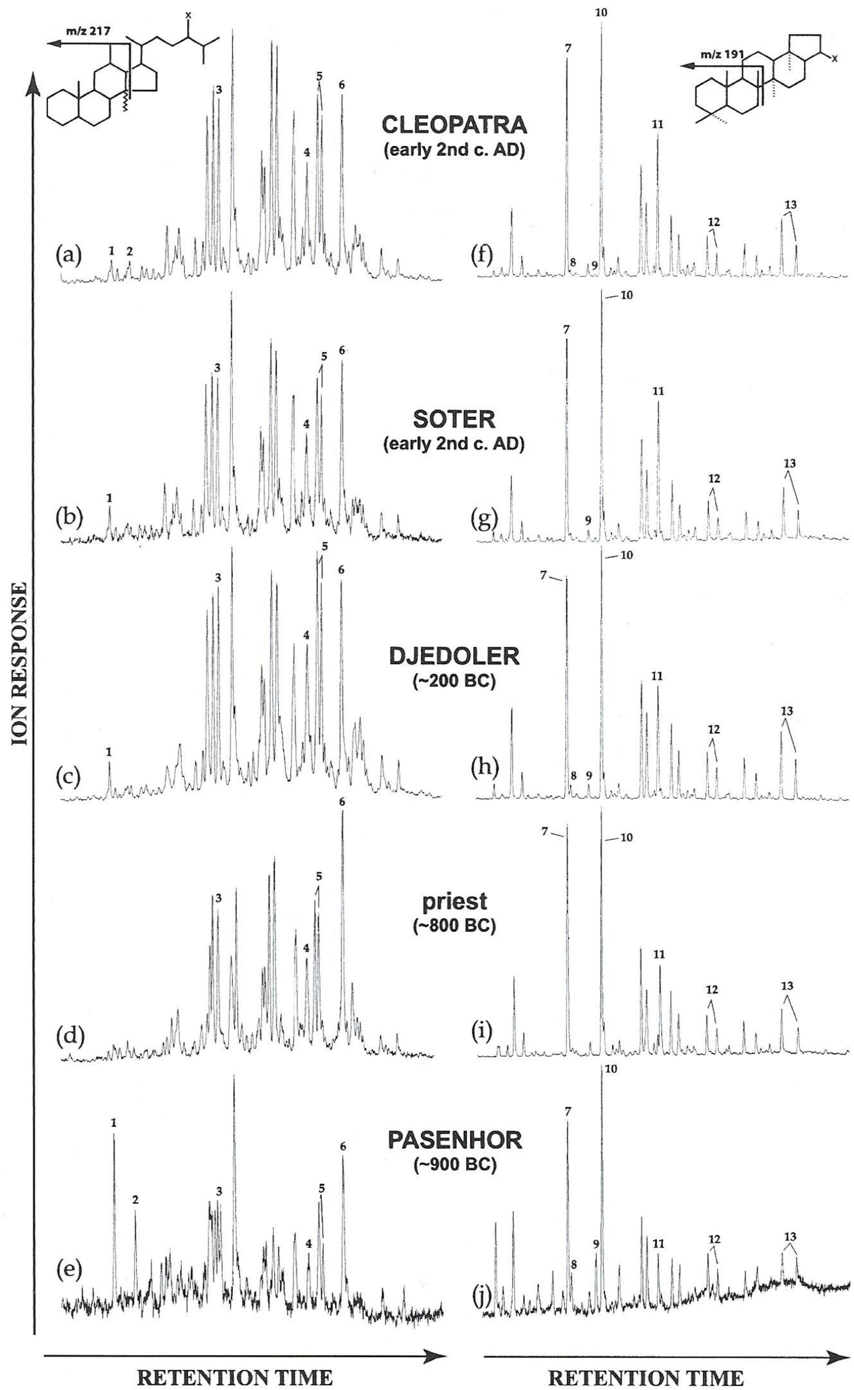

Figure 5 *Mummy bitumen chromatograms. Shown are the m/z 217.196 sterane ion fragments (a–e) and m/z 191.18 pentacyclic terpane ion fragments (f–j) in the saturate fractions of bitumen extracted with chloroform from the Cleopatra mummy (a, f), the Soter mummy (b, g), the Djedoler mummy (c, h), the priest mummy (d, i) and the Pasenhor mummy (e, j). The labelled reference peaks are the same as described in the caption of Figure 2.*

from the Cleopatra, Soter, Djedoler and Pasenhor mummies, and Sandra Knudsen (Toledo Museum of Art, USA) for furnishing the bitumen sample from the priest mummy. Appreciation is also extended to David King and Michael Pribil for sample preparation and GC/MS analyses, to Christopher French and Steven Cazenave for graphic illustrations, and to Les Magoon and Paul Lillis for reviewing the manuscript (all with the U.S. Geological Survey, USA). Thanks are additionally owed to the several pottery specialists who examined the ceramics from the Gebel Zeit seep, including Roberta Tomber (Museum of London, UK), Susan Allen, Salima Ikram and George Scanlon (American University in Cairo, Egypt), Michael Jones (American Research Center in Egypt), Sylvie Marchand (Institut Français d'Archéologie Orientale, Egypt) and Ashraf El Senussi (El Faiyum, Egypt).

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