New evidence for the geological origins of the ancient Delphic oracle (Greece)

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ABSTRACT

Ancient tradition linked the Delphic oracle in Greece to specific geological phenomena, including a fissure in the bedrock, intoxicating gaseous emissions, and a spring. Despite testimony by ancient authors, many modern scholars have dismissed these traditional accounts as mistaken or fraudulent. This paper presents the results of an interdisciplinary study that has succeeded in locating young faults at the oracle site and has also identified the prophetic vapor as an emission of light hydrocarbon gases generated in the underlying strata of bituminous limestone.

Keywords: Greece, normal faults, limestone, bitumen, travertine, ethylene.

INTRODUCTION

The sanctuary of Delphi is located on the southern slope of Mount Parnassus overlooking the gorge of the Pleistos River (Figs. 1 and 2), where a settlement was established in the late Bronze Age, ca. 1600 B.C. (Müller, 1992). The famous oracle, originally sacred to the Earth goddess (Ge) and later to Apollo, made Delphi a major religious center. Greeks, Romans, and Anatolian rulers consulted the oracle for guidance concerning private affairs, colonizing ventures, wars, and changes of government. The oracle ceased to operate in A.D. 392, when it was closed by order of a Christian emperor.

Ancient authorities attributed the prophetic power of the Delphic oracle to three geological phenomena: a fissure in the bedrock, a gaseous vapor, and a spring. When French archaeologists excavated the temple a century ago, they encountered no obvious traces of a chasm or rising gases (Courby, 1927) and therefore rejected the tradition of intoxicating vapors as a myth. To explain how the myth might have originated, twentieth century investigators have pointed to prominent geological features in the vicinity of Delphi such as the Kastalia gorge to the east of the sanctuary (Oppé, 1904) or the Korykian Cave to the north (Fontenrose, 1978). Most recently, a fracture associated with a prominent east-west fault below the Phaedriades has been suggested as the origin of the ancient tradition of an oracular chasm (Piccardi, 2000).

Since 1995 we have been conducting a joint geological and archaeological project that incorporates field surveys with chemical analyses of spring water and mineral deposits. The new data collected in the course of this project indicate that both fracturing and gaseous hydrocarbon emissions occurred at the site of the Temple of Apollo. Both were directly connected to the operation of the Delphic oracle. These findings represent the first scientific evidence that establishes the accuracy of the ancient reports about a chasm and vapors at the oracle site.

THE ORACLE

At Delphi the oracles were spoken by a local woman, called the Pythia, who acted as a medium for the god Apollo. Her state of trance could be induced only in the small enclosed chamber (*adyton*) below the floor level of the Temple of Apollo, adjoining a larger room for priests and consultants. Once inside the sunken chamber, the Pythia seated herself on a tripod and inhaled a gaseous emission rising from either a natural fissure or a spring (Holland, 1933).

During routine sessions, the Pythia appears to have been only mildly intoxicated (Fontenrose, 1978). She could recognize visitors in the outer room, understand their questions, and respond at times in poetic verse (Maurizio, 1995). According to the high priest Plutarch, however, if the Pythia was forced into the oracular chamber against her will, an abnormal and occasionally fatal state of delirium or frenzy might result.

Plutarch (1936) noted that in his day (end of the first century A.D.) the gaseous emission in the adyton was weak and unpredictable, but it had a sweet smell like perfume. Plutarch was aware that the vapors could reach the surface either as a free gas or in combination with spring water. In an attempt to account for a decline in the oracle's power over the 500 years before his own time, Plutarch theorized that the underlying rock might have run out of the vital essence that produced the gas. Alternatively, he suggested that the great earthquake of 373 B.C. (epicenter below the Gulf of Corinth, south of Delphi) had disrupted the flow of gas by closing the vents in the rock.

TECTONIC SETTING

Delphi is located on the northern flank of the Corinth rift zone, which cuts an eastward-widening swath through central Greece (Fig. 1). Motion between the African, Anatolian, and Eurasian plates puts Greece in a tectonic vise. The opening of the Corinth rift zone is only

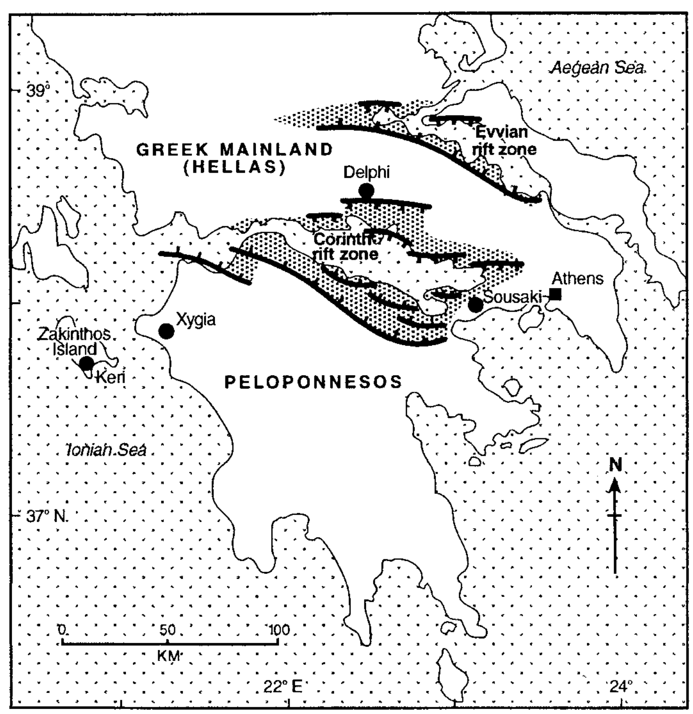

Figure 1. Tectonic setting of Delphi and schematic representation of Corinth and Evvian rift zones. Keri, Xygia, and Sousaki represent sites of hydrocarbon gas emissions mentioned in text.

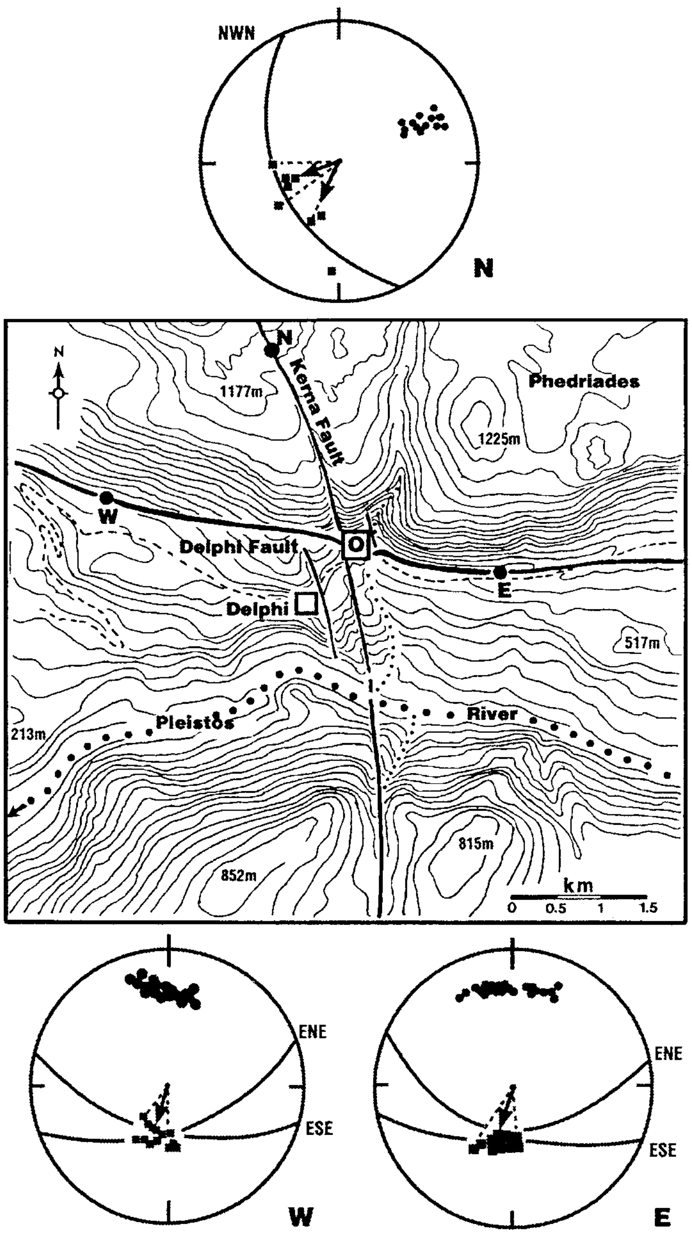

Figure 2. Topographic map of Delphi area and location of Kerna and Delphi faults. Stereographic projections (lower hemisphere) are of major fault surfaces (and slip directions) exposed north (*n* = 13), east (*n* = 22), and west (*n* = 18) of oracle site.

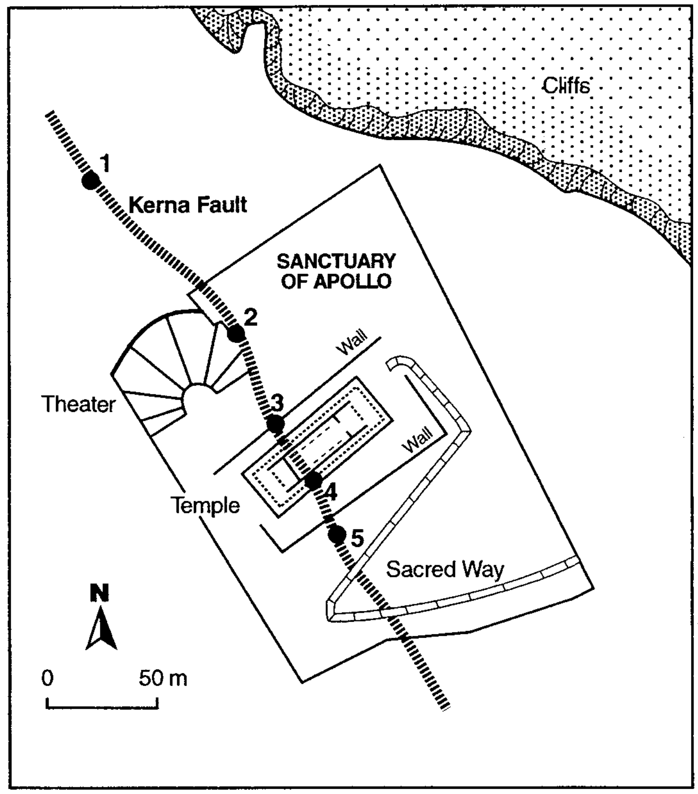

Figure 3. Trace of Kerna fault as outlined by line of five springs or related features in and directly outside sanctuary of Apollo. 1—Kerna Spring, 2—Theater Spring house, 3—travertine coating on Ischegaon retaining wall, 4—spring in temple foundation, near adyton, 5—former spring below sanctuary of Ge. Only Kerna Spring is active today.

one element in a general history of uplift and crustal stretching resulting from this confluence (Collier and Dart, 1991).

Each new episode of crustal extension widens the Corinthian Gulf as the peninsula of the Peloponnesos pulls farther south from the Greek mainland. In this highly fractured zone, characterized by normal faulting, long periods of gradually increasing strain are punctuated by major seismotectonic events (Ambraseys and Jackson, 1990; de Boer, 1992; Le Pichon et al., 1995; Armijo et al., 1996; Sorel, 2000). Energy released during such events causes earthquakes as well as frictional heating of the rock units along faults, both of which have proved crucial in the history of the Delphic oracle.

Records preserved in ancient sources show that the destruction of the Temple of Apollo in 373 B.C. may have been part of a more widespread tectonic event. In that year two small port towns, Helike and Boura, on the south shore of the Gulf of Corinth, disappeared below its waters during an earthquake (Mouyaris et al., 1992). Following this event, slip along an east-west–trending antithetic normal fault in the Delphic area destroyed the Temple of Apollo. Large surfaces of this fault are exposed both east and west of Delphi at short distances from the sanctuary (Fig. 2).

The southward-dipping Delphi fault extends below the ancient site of Delphi, but artificial terracing and erosional deposits obscure its trace in the vicinity of the temple. Detailed studies of this prominent tectonic feature have been published by Birot (1959), Pechoux (1992), and de Boer (1992).

During a field survey of the mountainside above Delphi, we discovered the exposed surface of a second major normal fault. This fault trends north-northwest and dips to the west (Fig. 2). The westward dip of the fault causes its surface trace to veer westward as it descends the cliffs to the sanctuary. Its southeastward continuation below the oracle site is shown by a more or less linear sequence of springs (Higgins and Higgins, 1996). We have named this structure the Kerna fault, after the Kerna Spring northwest of the temple (Figs. 2 and 3). The location of the fault as it passes under the Temple of Apollo is indicated by an ancient spring house built into the massive foundations, below and just to the south of the oracular chamber (Fig. 3).

The exact area of intersection of the Delphi and Kerna faults cannot be determined. Projections of fault trends, however, suggest that it is below the Temple of Apollo. The exceptionally dynamic geological situation at Delphi thus has its origins in the interaction between the Delphi and Kerna faults. Because cross-faulting happened to occur on a steep slope, the weakened mountainside underwent massive rock slides, forming the theater-like hollow backed by precipitous cliffs that

TABLE 1. HYDROCARBON GAS CONCENTRATIONS IN TRAVERTINE ROCK FROM THREE AREAS IN THE SANCTUARY AT DELPHI

Site	Methane	Ethane	Ethylene
Kerna Spring	0.13	n.d.	n.d.
Ischegaon Wall	1.16	0.04	n.d.
Temple of Apollo	2.82	0.03	n.d.

Note: Hydrocarbon concentrations are in ppm of volume of headspace; n.d.—not detected.

TABLE 2. HYDROCARBON GAS CONCENTRATIONS IN SPRING WATERS FROM DELPHI AND THE ISLAND OF ZAKYNTHOS

Location	Site	Methane	Ethane	Ethylene
Delphi	Kerna Spring	15.3	0.2	0.3
	Kastalia Spring	4.9	n.d.	n.d.
Zakynthos	Herodotus Spring	109.4	n.d.	0.1
	Xygia Spring	169.8	1.6	0.4

Note: Concentrations are in nM/L of water; n.d.—not detected.

forms the spectacular setting for the oracle. When ancient authors mentioned a chasm in the inner sanctum of the temple, they were most likely describing a minor extensional fracture associated with the northwest-trending Kerna fault, at or near its intersection with the Delphi fault. A photograph taken during the French excavations shows subvertical extensional fractures in the bedrock below the temple foundation (Courby, 1927).

EVIDENCE OF SPRINGS

Intersections of major fractures such as the Delphi and Kerna faults render the rock more permeable and provide pathways along which both groundwater and gases can rise. Springs were traditionally associated with the cult of Apollo at Delphi. Geological and archaeological evidence exists for as many as eight active springs in antiquity, although only the Kerna and Kastalia springs are still flowing today (de Boer and Hale, 2000). In the second century A.D., Pausanias (1935) observed a spring called Kassotis on the slope above the Temple of Apollo and stated that its waters plunged underground and emerged in the inner sanctum, where it made the women who drank from it prophetic. About A.D. 361, the Pythia claimed that she could give no more oracles because the temple had collapsed and the spring had fallen silent (Parke and Wormell, 1956).

Modern skepticism about gaseous emissions associated with springs at Delphi derives in part from an erroneous belief that only volcanic activity could produce vapors and gases (Amandry, 1950; Birot, 1959). In fact, the geological situation at Delphi is such that gases have been and continue to be produced in the bedrock underlying the oracle site. Although Paleocene flysch deposits (sandstone, shale, and conglomerate) occur at Delphi and in the Pleistos Valley, the local geology is dominated by a thick formation of Upper Cretaceous limestone. Some of its strata are bituminous, having a reported petrochemical content of as much as 20% (Aronis and Panayotides, 1960).

Seismotectonic activity increases the porosity and permeability of the rock units and can heat rock adjacent to faults to temperatures high enough to vaporize the lighter petrochemical constituents. Sulfur compounds, carbon oxides, and hydrocarbon gases can then be produced in the fault zones. Such emissions have been detected, for example, at Sousaki on the Isthmus of Corinth (east of Delphi) and at asphalt seeps on the island of Zakynthos (west of Delphi) (Dermitzakis and Alafousou, 1987). Higgins and Higgins (1996) suggested that the limestones at Delphi might have produced discharges of carbon dioxide, although this gas is not known to produce a euphoric trance.

ANALYSES OF GASES

Conditions for the introduction of intoxicating vapors were thus present at Delphi, along with a geological setting that could concentrate them at the intersection of two major faults. To identify the specific gases involved, we took samples of water from the Kerna Spring on the slope above the Temple of Apollo, as well as samples of travertine deposited by ancient springs. The springs below the sanctuary originated in deep limestone deposits and emerged along the Kerna fault at warm temperatures (Fig. 3), depositing travertine as the water cooled. We hoped that the travertine preserved a record of incorporated gases. We collected it from the surface of the ancient retaining wall (Ischegaon) directly north of the Temple, where a spring had deposited a stalactite mass of travertine on the masonry. Additional travertine samples were collected from fill inside the temple foundation, east of the inner sanctum, and from the Kerna Spring itself.

Using a headspace equilibrium technique (McAuliffe, 1971), we analyzed the water samples by gas chromatography. The travertine samples were placed in glass vials and stoppered; all air was removed by repeated vacuum evacuations and flushing with high-purity N_2 gas. The samples were then dissolved in 1*M* (molar) H_3PO_4 and the resultant headspace analyzed. Gases were identified by retention time and calibrated against known standards. The headspace to rock volume ratio in the vials was approximately 10 to 1. Detection limits were 0.01 ppm and 0.02 n*M*.

Hydrocarbon gases were detected within the travertine (Table 1). Methane (CH_4) in concentrations of 1–3 ppm was found in the headspace of vials containing dissolved samples collected from the Ischegaon wall and the temple, and ethane (C_2H_6) was present in all samples but those from the Kerna Spring. The vials were evacuated and several times filled with high-purity N_2; the headspace/rock ratio was 10. These results showed that at Delphi the spring waters brought light hydrocarbon gases to the surface in such volumes that some gas was trapped in the rapidly forming travertine.

The unusual nature of the spring water from the oracle site was emphasized by two comparisons. First, an analysis of water from the cold Kastalia Spring, located in a gorge ~100 m east of the temple, yielded only methane, at a level one-third that of the Kerna Spring waters. This finding suggests that the sites of hydrocarbon emissions at Delphi vary in output and are rather localized. Second, analysis of spring waters from the island of Zakynthos (Fig. 1) produced results that matched the types of gases from the Kerna Spring. The Keri site on Zakynthos is famous for its gas springs and tar pits (Dermitzakis and Alafousou, 1987). The latter deposits were used by ancient mariners to tar the hulls of their ships. The similarity of the composition of the spring waters sampled on Zakynthos and in Delphi confirms the link between hydrocarbon emissions and high concentrations of petrochemicals in the bituminous formations below these sites.

The modern Kerna Spring water yielded traces of ethylene (CH_2), another light hydrocarbon gas. Ethylene in particular was probably a significant component in the oracular sessions, because it has a sweet smell, which fits the description by Plutarch of vapors rising into the adyton.

First identified scientifically in 1865, ethylene was used as a surgical anesthetic in the early twentieth century. Under the influence of light doses, breathing is slow but regular, and the subject remains in full control of the body (Goodman and Gilman, 1996). Ethylene causes an excitation of the central nervous system.

The effect of low concentrations of ethylene is a sensation of floating or disembodied euphoria, with a reduced sense of inhibition. In some cases a more violent reaction may occur, including delirium and frantic thrashing of the limbs. Eventually, the anesthetic properties of ethylene can cause complete unconsciousness or even death. Plutarch (1936) described an event in which the Pythia died as a possible

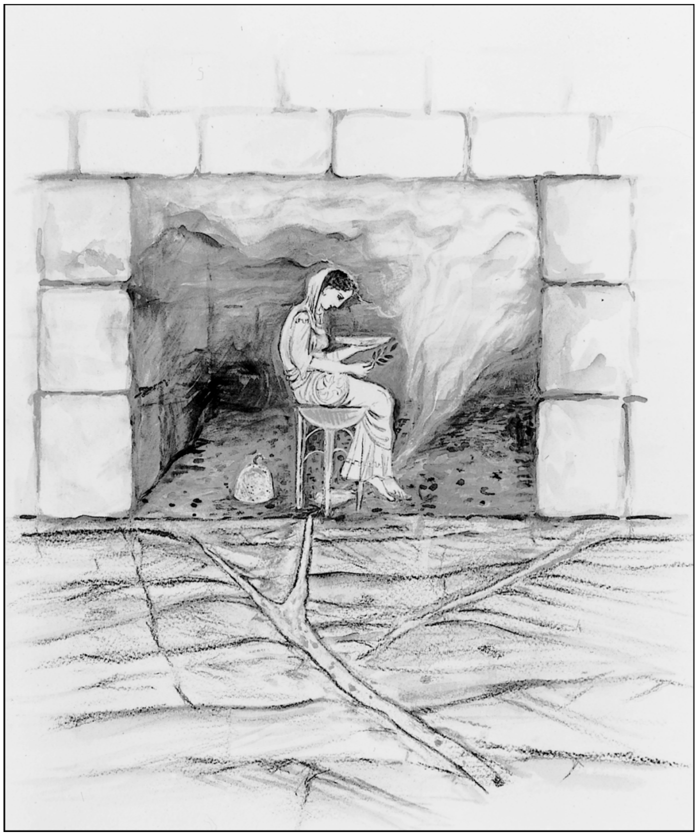

Figure 4. Sketch of Pythia in adyton, showing fractures from which gaseous vapors rose into narrow space during a mantic session.

consequence of such an overdose. The effects of low-level intoxication wear off quickly once the subject has been removed from contact with the gas (Lockhardt and Carter, 1923).

CONCLUSIONS

Contrary to current opinion among many archaeologists and some geologists, the ancient belief in an intoxicating gaseous emission at the site of the Delphic oracle was not a myth. An unusual but by no means unique combination of faults, bituminous limestone, and rising groundwater worked together at Delphi to bring volatile hydrocarbon gases to the surface. Ethane, methane, and ethylene all emerged, and modern research has shown that the effects of ethylene inhalation match the well-documented effects of the ancient prophetic vapors. The Temple of Apollo was constructed directly over an area of cross-faulting in order to enclose this unique occurrence and provide a setting for the oracle that was both dramatic and functional in terms of concentrating the gases in a constricted, poorly ventilated chamber above the source (Fig. 4). Our research has confirmed the validity of the ancient sources in virtually every detail, suggesting their testimony on geology is of more value than has recently been held to be the case.

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