Supplementary Content: Appendices

Appendices to accompany the *American Journal of Archaeology* publication:

Processions, Propaganda, and Pixels: Reconstructing the Sacred Way Between Miletos and Didyma

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Appendix 1. Inscriptions, Molpoi Stations, Sondages, and Archaeological Features Relating to the Sacred Way Between Miletos and Didyma

Table 1**.** Inscriptions relevant to the Sacred Way (detailed version, with references).

No.	Name (Language), = Alternative Identifiers[a]	Manufacture Date	Discovery Date (Find Context)	Textual Reference(s) to Road	Publication (Current Location)
i1	Molpoi inscription/ Molpoi statutes (Greek)	ca. 200 B.C.E. (text composition date could be 530–200 B.C.E.?)	1903 (Miletos, Sanctuary of Apollo Delphinios, in situ)	ὁδὸς πλατεῖα = "wide road"	Rehm 1914, 277–84; Herda 2006 (Pergamon Museum)
i2	gravestone for Bitto or Bittion (Greek) =Did. II, no. 537	ca. 200 B.C.E.	ca. 1895 (Didyma, "in the house of Manubis Anais")	ὅτ᾽ ἱερὸν ἤγ[αγεν οἶμον] = "sacred [way]"	Peek 1971, 211–13 no. 10; Herda 2006, 181 n. 1287 (location unknown)
i3	building inscription (describing repairs) (Greek) =Did. II, no. 40	ca. 200–175 B.C.E.	1896 (Didyma, "on the land of Papa Dimitriu")	ἱερᾶς | ὁδοῦ = "sacred way"	Rehm 1958, no. 40 (Didyma Kazı Evi?)
i4	Sacred Gate inscription (Trajan's works) (Latin) =Mil. II, 3 no. 402 =E/W, Milet 1	101/2 C.E.	1873 (Miletos, in situ at Sacred Gate)	*viam necessariam [s]acris Apollinis Didymei* = road essential for the rites of the Didymeian Apollo *excisis collibus completis vallibus* = cutting of hills, filling of valleys	von Gerkan 1935, 32–3, fig.3, 133–34 no. 402; Herrmann 1997, 217 no. 402; Ehrhardt and Weiß 2011, 224–27 no. Milet 1 (Miletos, where found)
i5	Trajan's works (Greek) =E/W, Milet 2	101/2 C.E.	1997 (possibly recovered from secondary usage in Akyeniköy?)	text seems to be fragmentary Greek version of i4	Ehrhardt and Weiß 2011, 222–24; 227 no. Milet 2 with fig. 2 (Milet Museum, inv. no. 1883)

i6	Trajan's works, bilingual two-sided stele =Mil. I, 7 no. 272 a and b =E/W, Milet 3	101/2 C.E.	1901 (Miletos, stone reused as capital in Byzantine era, hence not in situ)	text seems to be fragmentary bilingual version of i4	Rehm 1914, no. 272 a and b (= *CIL* III 14403); Ehrhardt and Weiß 2011, 227–30 no. Milet 3 with figs. 6–8 (location unknown)
i7	Trajan's works, stele fragment (Latin) =Tuchelt 1973:1e =Did. II, no. 55 =E/W, Didyma 1	101/2 C.E.	1909 (Didyma, in a garden to the northwest of the village of Yoran; not in situ; possibly connected with fragment from east side of the temple)	text seems to be fragmentary Latin version of i4	Tuchelt 1973, 25–6, pl. 6; Ehrhardt and Weiß 2011, 227–30 no. Didyma 1 with fig. 9 (Didyma Kazı Evi, inv. no. E 6)
i8	Trajan's works, stele fragment (Greek) =Tuchelt 1973:1f =Did. II, no. 56 =E/W, Didyma 2	101/2 C.E.	1909 (Didyma, in the village, not in situ)	text seems to be fragmentary Greek version of i4	Tuchelt 1973, 25–6, pl. 6; Ehrhardt and Weiß 2011, 231 no. Didyma 2 (no figure) (Didyma Kazı Evi, inv. no. E 45)
i9	Trajan's works, bilingual two-sided stele =Tuchelt 1973:1g =Did. II, no. 55 (Latin) =Did. II, no. 56 (Greek) =E/W, Didyma 3	101/2 C.E.	1972 (Panormos, in well next to a canal in Subatak, near the Panormos harbour, not in situ)	text seems to be fragmentary bilingual version of i4	Tuchelt 1973, 25–6, pl. 6; Ehrhardt and Weiß 2011, 232–34 no. Didyma 3 with figs. 10, 11 (Didyma Kazı Evi, inv. no. E 128)
i10	milestone, Trajanic (Latin and Greek) =Did. II, no. 57 =Tuchelt 1973:1d =E/W, C =Fr, no. 123(A)	101/2 C.E.	1909 (Didyma, near the Straßentor/street gate and sacred way to northwest of temple, apparently not in situ but not far from the road)	*ὁδὸν* | *ἱερὰν* = "sacred way"	Tuchelt 1973, 26, pl. 6; Ehrhardt and Weiß 2011, 234–36 no. C with fig. 12 French 2014, 228 (Didyma, where found)

i11	milestone, Julianic (Greek w/ Roman numerals) =Did. II. no. 60 =Fr:123(B)	362/3 C.E.	unknown, 1909? (unknown?)	Milestone with distance to Miletos set at 4 Roman miles; no direct mention of Sacred Way; cut onto the back of a base for a statue of Constantius Chlorus II	Rehm 1958, 139 Ehrhardt and Weiß 2011, 260 with n. 137 French 2014, 228–9 (location unknown)

[a] The alternative identifiers reflect the way these inscriptions have often been referred to in past publications. They are provided here to aid the reader to navigate the literature more easily (Did. II = Rehm 1958; Mil. I = Rehm 1914; Mil. II = von Gerkan 1935; E/W = Ehrhardt and Weiß 2011; Fr = French 2014).

Table 2. Processional stations implied or mentioned on the Molpoi inscription and their possible archaeological correlates (following Herda 2006).

Station	English Translation	Possible Location or Correlate (see table 4)
[implicit]		Altar of Sanctuary of Apollo Delphinios, Miletos
Γυλλοὶ φέρονται δύο	Gylloi, placed at gate	near Sacred Gate at Miletos (a1)
Ἑκάτην	the Hekate	unknown
Δυνάμει	Dynamis	unknown
Νύμφαισ᾽, εἶτεν παρ	grassland on the Akron Hills where the Nymphs are	Sanctuary of the Nymphs (a5)
Ἑρμῆ ἐν Κελάδο	Hermes in Kelados	unknown
Φυλίωι, κατὰ Κεραΐτην	Phylios in the area of *Keraiites* (the horned)	unknown
Χαρέω ἀνδριάντες	the statues of Chares	Branchidae? (a11, but location of statues may have changed)
[implicit]		Altar of Temple of Apollo, Didyma

Table 3. Archaeological sondages on the peninsula relevant to the Sacred Way, ordered by date of investigation (detailed version, with references).

No.	Location (Name[s])	Sondage Date (Est. Dimensions)	Road or Context Description	References
s1	Sacred Gate, Miletos (sondage A)	1903 (ca. 4 x 20 m); trench dug along front of the Sacred Gate	width of road, ca. 11.40 m, reducing rapidly to ca. 4.5 m; wide curbstones (0.7 m); Archaic levels, including cremation burials, were reached, but earliest stratigraphic layers not well published	von Gerkan 1935, 32; Forbeck 1998, 149–51, n.184, figs. 63, 64
s2	northwest of Didyma, now known to be near to paved street, (trenches I, II, III, IV, V, VI, VII, VIII, IX)	1906 (mostly ca. 2 x 5 m); a series of relatively small trenches, laid across sections of the presumed line of the Sacred Way by von Gerkan	paved street revealed under ca. 2 m of soil in trenches I–VIII; an additional side street identified next to a propylon gate (in later publications called a *Torbau*) in trench VII	Knackfuß 1941, 156–58
s3	near the Straßentor, Didyma (trenches A, B, C, D, E, F, G, H, I, K)	1938 (?)	these works undertaken by Krauss appear to have been primarily designed to measure visible features	Knackfuß 1941, 156–58
s4	paved street, Didyma (*Südsondage*)	1972 (1.5 x 5.5 m across street, 10 x 1 m along street); a T-shaped sondage through a robbed section of the paved street and along the side of the street; re-examined and extended in 1983	series of horizons below paved level, including probable Hellenistic compacted gravel road; lowest levels were less clear and difficult to differentiate; no unequivocal pre-Hellenistic road level.	Tuchelt 1984, 214–15
s5	paved street, Didyma	ca. 1977–1983; large open area excavation across paved street (next to structure believed at the time to be an Artemis sanctuary), overlapping with von Gerkan's earlier sondages	carefully and regularly shaped limestone blocks used to pave latest level of street; width 4.90–5 m for a length of 75 m.	Tuchelt 1984, 224, n. 38; 1987, 78–9; 1990, 95

s6	paved street, Didyma (*Nordsondage*)	1983 (3 x 6 m); sondage through a robbed section of the paved street; excavation to deepest level only in around 20% of the trench	stratigraphy matches that of s8 (the *Südsondage*), with greater clarity; at the northeastern side of this sondage was found the so-called Archaic *Grenzstein*.	Tuchelt et al. 1984, 214–15
s7	Archaic Cult Complex, Akron Hills (trench TEM1)	1985 (4 x 9 m); thin sondage oriented perpendicular to road, taking in road and wall above	pavement from limestone blocks (cut from bedrock?), no datable finds; width of road unclear, 5.3–6.3 m.	Tuchelt et al. 1996, 4–5, 118, 203 (TEM1, prev. SON 2)
s8	near Straßentor, Didyma (sondages SS 87/A1, SS 87/A2, SS 87/B1, SS 87/B2, SS 87/C, SS 87/D, SS 87/F, SS 87/G, SS 87/H1, SS 87/I, SS 87/K, SS 87/M)	1987 (various; SS 87/B1 = 3 x 8 m, SS 87/B2 = 3 x 6 m); a series of sondages of different sizes spread along the area between the petrol station and the paved street at Didyma	no synthesis of the finds, structures, or stratigraphy has yet been prepared, but an interim scan of the notebooks suggests that, even though various finds date back to the Archaic era, there is no clear evidence for pre-Hellenistic road horizon; the majority of the evidence from this area is Hellenistic, Roman, or Byzantine.	unpublished, see excavation diaries: Tuchelt 1985–1986; 1986–1987, esp. plans showing location on 1534c and 1534e
s9	Sanctuary of the Nymphs, Akron Hills (sondage SS 94/18)	1994 (ca. 2 x 6 m); clearance or shallow sondage downhill of terrace of stone blocks (across track)	pavement from limestone blocks (cut from bedrock?), matrix of mixed Archaic and Hellenistic sherds; no datable horizon; width of road not recorded; Schneider's earlier sketch suggests ca. 5 m.	Bumke et al. 2000, 91–2, figs. 3, 28
s10	Sanctuary of the Nymphs, Akron Hills (sondage SS 94/07)	1994 (3 x 4 m); shallow excavation uphill of terrace of stone blocks	not completely excavated to the wall; coin find used to suggest fourth/third century B.C.E. date; a thin layer perhaps representing an Archaic path	Bumke et al. 2000, 90–1, figs. 3, 28
s11	between paved stretch and temple, Knackfuß House, Didyma (sondage HSA)	2008 (ca. 2.6 x 5 m); deep sounding next to modern road and the so-called Knackfuß House	no road identified, large amounts of mixed (including Byzantine) material; and a Hellenistic statue base; deepest detectable horizon seems to have been Hellenistic in date	Furtwängler 2009, 7–9; Slawisch 2013, 57–8

s12	around Mavişehir along projected route of Sacred Way	2011 (series of small sondages ca. 2 x 1 m); excavated by the museum	no clear road surfaces identified	unpublished, see Milet Museum field report archives
s13	Panormos Necropolis (sondage S1)	2012 (5 x 2.5 m); sondage in the middle of a field in the valley assumed to carry the Sacred Way	up to 2 m of post-Archaic sedimentation in the middle of the valley; no evidence of paved or other road	Slawisch 2014, 116; final report not yet published
s14	east end of the paved stretch, next to modern road, Didyma	2013 (small sounding)	paving continues a few more meters until bedrock block, after which the road could not be identified	Bumke et al. 2015, 472, fig. 7 (Area "B," north)
s15	between paved stretch and temple, Didyma	2014 (small deep sounding under modern road)	no pavement identified; large amounts of mixed fill (including Late Roman and Byzantine)	Bumke et al. 2015, 472, fig. 7 (Area "B," south)
s16	between mosque and temple, south of modern mosque, Didyma	2015 (small deep sounding under modern road)	no pavement identified; disturbance context with mixed fill (Late Roman Byzantine)	Bumke et al. 2016, 397, fig. 8 (Area "C")

Table 4. Reported archaeological structures, remains, and finds relating to or located near or along the possible route(s) of the Sacred Way, ordered north to south (detailed version, with references).

No.	Name(s) or Description	Construction Date(s)	Disc. Date	Detailed Context or Description	References
a1	Sacred Gate, Miletos (including paved street)	Older Sacred Gate: Hellenistic Younger Sacred Gate: Hellenistic to Roman (renovated under Trajan?)	1873	large gate structure at entry to city of Miletos, with wide section of paving on the inner side of the Younger Gate; and possible stratified Hellenistic to Roman road surfaces and associated curb-stones on outer side of the Older Sacred Gate; plus necropoleis and grave monuments outside of Older Gate	von Gerkan 1935, 31, 32–4, 133–34, figs. 13, 14, pl. 6.8; Forbeck 1998, 149-57; Wiegand 1929, 9
a2	terrace-like wall and stone-scatters, north slopes of Akron/Stefania Hills	(undetermined)	1986?	terrace-like walls and stone scatters that may represent difference phases of road-construction (not mapped)	Schneider 1987, 106
a3	Wilski's Antike Strasse, Akron Hills	ancient? (curbstones likely to be post-Archaic)	1899?	long stretch of roadway	Wilski 1906
a4	Archaic Cult Complex, Akron Hills	Archaic (sixth century B.C.E.)	1984	building complex next to Wilski's Antike Strasse	Gödecken 1986; Tuchelt 1989
a5	Sanctuary of the Nymphs/Quellbezirk, Akron Hills	Archaic, Hellenistic, and Roman	1901	Building complex with spring next to Wilski's Antike Strasse	Bumke et al. 2000
a6	Panormos Necropolis	Archaic	2012	Archaic necropolis, but no evidence for road	Slawisch 2014; awaiting full publication
a7	*Landungssste*/jetty at Panormos (modern Mavişehir)	(undetermined)	ca. 1901	stone blocks apparently used for mooring boats (or discarded building blocks) at the Panormos harbor: now obscured by modern pier and reclaimed land	Schneider 1987, 117 n. 54
a8	sherd cluster (possible farmstead) in the Subatağı Mevkii area	Roman?	2015	high density of Roman sherds on the northern side of the Sulubatak Valley; the area is devoid of earlier (e.g., Archaic) finds suggesting a post-Archaic accumulation of sediment in the area	a8

a9	sherd clusters (possible building?) at Panormos (modern Mavişehir)	Archaic?	2015	very high density of Archaic sherds lying on hill spur above presumed route of Sacred Way, discovered as part of Panormos Survey	final report not yet published
a10	series of stone sarcophagi near Didyma	Hellenistic/Roman?	1812	series of stone sarcophagi or their lids lying within or next to the presumed route of the Sacred Way	Schneider 1987, fig. 19
a11	Branchidae (seated stone statues) near Didyma, collected by Newton	Archaic	1812	statues along presumed road northwest of Didyma but apparently not in original location	Gell 1819; Tuchelt 1970, 18, 78–80 K 47
a12	Straßentor (Street Gate), or Fundament structure near Didyma	Archaic/Hellenistic/ Roman(?)	1907	fragmentary remains of structure suggested as possible Street Gate (and therefore the entrance to the sanctuary area); on reexamination, only one side could be identified, and the structure may represent a base for statues	Knackfuß 1941, 156; Tuchelt 1973, 16, 17, 25, 96, 97; see also unpublished notebooks from Tuchelt 1986–1987
a13	*Grenzstein* (cylindrical boundary stone) near Didyma	Archaic(?)	1983	cylindrical stone, found in the *Nordsondage*, argued to represent a boundary stone but bears no inscription	Tuchelt et al. 1984, 224; Herda 2006, 257 n. 1827
a14	paved street at Didyma (locally, "the Sacred Way")	Roman (Trajan?)	1970s	long section of paved limestone street from Didyma heading towards Panormos, lined by buildings (shops?)	e.g., Tuchelt et al. 1984, 224, n. 38
a15	grave monuments near Islamyoran (northeast of Didyma)	Hellenistic/Roman	1996–1998	remains of probable Hellenistic and Roman grave monuments near Islamyoran (S242), Yedizeytinlik Sırt (S401, S402), and Yassı Tepe (S248); numbers refer to site catalogue in Lohmann 1999	Lohmann 1999

Works Cited

Bumke, H., A. Herda, E. Röver, and T.G. Schattner. 2000. "Bericht über die Ausgrabungen 1994 an der Heiligen Straße von Milet nach Didyma: Das Heiligtum der Nymphen?" *AA*:57–97.

Bumke, H., F. Bertemes, H. Cevizoğlu, and E. von Gaisberg. 2015. "Didyma 2013." *Kazı Sonuçları Toplantısı* 36(2):467–88.

Bumke, H., H. Cevizoğlu, E. von Gaisberg, F. Bertemes, and A. Tanriöver. 2016. "Didyma 2014." *Kazı Sonuçları Toplantısı* 37(3):391–416.

Ehrhardt, N., and P. Weiß. 2011. "Eine monumentale Dankesgabe: Trajans Neubau der Heiligen Straße von Milet nach Didyma." *Chiron* 41:217–62.

Forbeck, E. 1998. "Die Nekropolen von Milet: Die Grabungen 1901 bis 1909 und die Arbeiten der Jahre 1993 bis 1996." Ph.D diss., Ruhr-Universität Bochum. http://hss-opus.ub.ruhr-uni-bochum.de/opus4/frontdoor/index/index/docId/4915.

French, D. 2014. *Roman Roads and Milestones of Asia Minor*. Vol. 3, *Milestones*. fasc. 3, part 5, *Asia.* BIAA Electronic Monograph 5. Ankara: British Institute at Ankara. http://biaa.ac.uk/publications/item/name/electronic-monographs.

Furtwängler, A.E. 2009. "Didyma: Ein Überblick über die jüngeren Forschungen." *Colloquium Anatolicum* 8:1–17.

Gell, W. 1819. *The Itinerary of Greece: Containing One Hundred Routes in Attica, Boeotia, Phocis, Locris, and Thessaly*. London: John Rodwell.

Gödecken, K.B. 1986. "Beoachtungen und Funde an der Heiligen Strasse zwischen Milet und Didyma, 1984." *ZPE* 66:217–253.

Herda, A. 2006. *Der Apollon-Delphinios-Kult in Milet und die Neujahrsprozession nach Didyma. Ein neuer Kommentar der sog. Molpoi-Satzung*. Milesische Forschungen 4. Mainz: Philip von Zabern.

Herrmann, P. 1997. *Inschriften von Milet Teil 1, B. Nachträge und Übersetzungen zu den Inschriften n. 1–406*. Berlin: Walter de Gruyter.

Knackfuß, H. 1941. *Didyma.* Vol. 1, *Die Baubeschreibung: In drei Bänden*. Berlin: Gebr. Mann.

Lohmann, H. 1999. "Survey in der Chora von Milet: Vorbericht über die Kampagnen der Jahre 1996 und 1997." *AA*:439–73.

Peek, W. 1971. “Griechische Versinschriften.” *ZPE* 7:193–226.

Rehm, A. 1914. “Die Inschriften.” In *Das Delphinion in Milet*, edited by G. Kawerau and A. Rehm, 162–406. Milet 1(3). Berlin: Georg Reimer.

———. 1958. *Didyma*. Vol. 2, *Die Inschriften*. Berlin: Gebr. Mann.

Schneider, P. 1987. “Zur Topographie der Heiligen Straße von Milet nach Didyma.” *AA*:101–29.

Slawisch, A. 2013. “Didyma: Untersuchungen zur sakralen Topographie und baulichen Entwicklung des Kernheiligtums vom 8.-4. Jh. v. Chr.” In *Heiligtümer: Gestalt und Ritual, Kontinuität und Veränderung. Sanktuar und Ritual Heilige Plätze im archäologischen Befund*, edited by I. Gerlach and D. Raue, 53–60. Forschungscluster 4. Rahden: Marie Leidorf.

———. 2014. “e-Projektbericht: Die archaische Nekropole von Panormos, 2012 und 2013.” *eDAI-F 2014*-3:114–19.

Tuchelt, K. 1970. *Die Archaischen Skulpturen von Didyma, Beiträge zur frühgriechischen Plastik in Kleinasien*. *IstForsch* 27. Berlin: Mann.

———. 1973. *Vorarbeiten zu einer Topographie von Didyma: Eine Untersuchung der inschriftlichen und archäologischen Zeugnisse*. *IstMitt-BH* 9. Tübingen: E. Wasmuth.

———. 1984. “Didyma: Bericht über die Arbeiten der Jahre 1980–1983.” *IstMitt* 34:193–344.

———. 1985–1986. “Didyma-Grabung, Tagebuch 2/5, 1985 II. 1986. I (1144–1338).” Unpublished field notebook. Berlin: DAI, Didymaarchiv.

———. 1986–1987. “Didyma-Grabung Tagebuch 2/6, 1986 II. 1987 (1339–1534).” Unpublished field notebook. Berlin: DAI, Didymaarchiv.

———. 1987. “Bericht über die Arbeiten der Didyma-Grabung 1986.” *Kazı Sonuçları Toplantısı* 9(2):77–81.

———. 1989. “Bericht über die Arbeiten der Didyma-Grabung 1988.” *Kazı Sonuçları Toplantısı* 11(2):43–52.

———. 1990. “Didyma-Grabung 1989.” *Kazı Sonuçları Toplantısı* 12(2):95–104.

Tuchelt K., P. Schneider, T.G. Schattner, and H.R. Baldus. 1996. *Ein Kultbezirk an der Heiligen Straße von Milet nach Didyma*. Didyma 3(1). Mainz: Philipp von Zabern.

von Gerkan, A. 1935. *Die Stadtmauern*. *Milet* 2(3). Berlin: Walter de Gruyter.

Wiegand, T., ed. 1929. *Die milesische Landschaft*. *Milet* 2(2). Berlin: Hans Schoetz und Co.

Wilski, P. 1906. *Karte der Milesischen Halbinsel (1:50000): Mit erläuterndem Text*. *Milet* 1(1). Berlin: Georg Reimer.

Appendix 2. Route Modeling of the Sacred Way Between Miletos and Didyma

An Open-Source Explanation Using R Code and Libraries

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INTRODUCTION

This annex paper provides a walkthrough of the analytical procedures used to produce maps to understand the possible variations in route of the so-called Sacred Way between the ancient city of Miletos and its sometime-dependent oracle sanctuary at Didyma. It should be read in conjunction with and as support for the archaeologically and epigraphically oriented arguments in:

- **A. Slawisch and T.C. Wilkinson. 2018. "Processions, Propaganda and Pixels: Reconstructing the Sacred Way Between Miletos and Didyma."** ***American Journal of Archaeology*** **122(1):101–43.**

This analysis attempts to compare the generally-assumed or orthodox reconstruction of the Sacred Way between Miletos and Didyma with mathematically-derived or probability-based models of travel across a landscape. These models are called, variously, cost-surface, resistance or friction-surface analyses. They should, of course, be treated as heuristic rather than truly-predictive models, providing a visualization of "what we would expect" if travel friction or cost were an important part of the decision-making in routing a particular path. Such cost factors can contribute to path generation either from rational decision-making (in the case of modern or ancient road building) or organically through a process akin to Darwinian selection (i.e., those taking the least-cost path are most successful from an energy/time-expenditure point of view).

NATURE OF THIS DOCUMENT

This appendix is generated from an R Markdown document, which depends on external packages from the CRAN repositories. For more details on using R Markdown see http://rmarkdown.rstudio.com.

The static version you are currently reading was created on 2017-08-23, with minor manual modifications made 2017-11-13. The core content has not changed since the date of the document described above (2017-07-23).

NB: Procedures to create the necessary stages of analysis are shown here as R functions with the prefix `sw_`, for clarity where similar procedures are preformed and to increase ease of re-use within this text and by others.

```
# testing time of procedure
ptm <- proc.time()
```

This script relies on a number of libraries from the CRAN directory which must be installed before the full script can be run. Libraries are loaded before data import and calculations. It is recommended that R packages are installed manually before the script is run, as the set-up process can be different on different systems.

```
# Install the libraries It is recommended to
# install these packages manually per machine
# where possible, since some machines (e.g.
# Mac OS X) require a different version of
# RGDAL to function. See
# http://www.kyngchaos.com/software/frameworks
# for Mac OS X rgdal package.
# install.packages(c('knitr', 'sp', 'rgdal',
# 'plyr', 'dplyr', 'RColorBrewer',
# 'gdistance', 'maptools', 'rgeos'),
# repos='https://mirrors.ebi.ac.uk/CRAN/')

# Load the libraries
library("sp")
library("rgdal")
library("plyr")
library("dplyr")
library("RColorBrewer")
library("gdistance")
library("maptools")
library("rgeos")
# library(raster) #already required by other
# packages
```

DEFINE FIXED VARIABLES

Established default projection

Output for the maps will use the UTM 35N projection.

```
projection <- c(paste("+proj=utm +zone=35n ",
    "+datum=WGS84 +units=m ", "+no_defs +ellps=WGS84 ",
    "+towgs84=0,0,0", sep = ""))
```

LICENSING OF CODE

Since the aim of this paper is to facilitate replication of our results and provide the opportunity for future alternative interpretations, the source code presented is licensed using a Creative Commons (CC) BY license which means that others are allowed to create derivative works provided the original source (i.e., this document) and the authors are cited.

GIS DATA AND EXTERNAL FILES

This paper is designed to be used in association with geographical data which forms part of the Project Panormos archive. Those wishing to reproduce the analysis will need both the necessary R environment and the referenced data. Distributable data will ultimately be made available via http://www.projectpanormos.com/sacredway/ .

LOAD BASE SPATIAL DATA

The RMarkdown document assumes that it resides in a directory called `sacredway-analysis/rcode` and that relevant external data files are to be found relatively in the top level folder above `sacredway-analysis`.

```
## Script expects to find itself in
## topfolder/sacredway-analysis or similar
## depth relative to other data so that it can
## find the sacredway-data repository etc.
## Change this if the data directory structure
## is different.  the final / slash is
## essential
working_dir <- "../../"
```

The external data is contained in the following required repositories which must reside in a folder next to `sacredway-analysis`:-

- `sacredway-data` - which includes spatial data files relating to the location of the Sacred Way, earlier reconstructions and points along the Sacred Way; plus land-shapes to allow derivation of the ancient coastline around the Milesian peninsula
- `gis-static/dem/` - a DEM needs to be downloaded by users. In the original version, the DEM used was an ASTER GDEM v2. For identical results, the same tile should be downloaded, unzipped into the relevant files into `gis-static/dem/aster/ASTGTM2_N37E027/` with the relevant file being `ASTGTM2_N37E027_dem.tif`.

The ASTER GDEM v2 data-set can be downloaded via: https://gdex.cr.usgs.gov/gdex/ or https://reverb.echo.nasa.gov/reverb/ or https://search.earthdata.nasa.gov/, most directly by: https://search.earthdata.nasa.gov/search/granules?p=C197265171-LPDAAC_ECS&g=G198033961-LPDAAC_ECS&m=36.9404296875!26.738525390625!7!1!0!0%2C2&sb=27.06591796875%

2C37.30517578125%2C27.64599609375%2C37.6171875&fst0=Land+Surface&fsm0=Topography.

Alternatively this DEM can be replaced by any equivalent compatible raster which covers the same region and can be reprojected without inappropriate data loss (i.e., of sufficient resolution) to the project coordinate system. The code will need to be modified to load this data.

Additional inessential files are used in the published version for data that we are not currently entitled to distribute. These reside in the following repositories:

- `gis-active-vector` - which includes modern road ways and place names, as well as site distributions from Lohmann's extensive survey of the Milesian peninsula
- `gis-active-raster` - which includes a DEM derived from Wilski's contour map
- `gis-static/imagery/` - which includes WorldView satellite imagery

Note: the majority of the spatial files are stored in GML format. Take care not to save any fields as Integer64 format as this may create difficult to trace errors when files are loading.

Exported results

Results of the analysis are exported to the `sacredway-data/results` folder.

```
# the directory to which exported layers are
# saved
export_dir <- "../../sacredway-data/results/"
export_dir <- normalizePath(export_dir)
```

Load archaeological points-of-interest along the Sacred Way

```
point_sacred_gate <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "points_along_the_sacred_way/miletos_sacredgate.gml",
    sep = ""), layer = "miletos_sacredgate", encoding = "UTF-8")

point_didyma_altar <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "points_along_the_sacred_way/didyma_alter_point.gml",
    sep = ""), layer = "didyma_alter_point", encoding = "UTF-8")

point_road_leaving_akron <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "points_along_the_sacred_way/road_as_leaves_hills_point.gml",
    sep = ""), layer = "road_as_leaves_hills_point",
    encoding = "UTF-8")

point_cult_complex <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "points_along_the_sacred_way/sw_point_archaic_cult_complex.gml",
    sep = ""), layer = "sw_point_archaic_cult_complex",
```

```
    encoding = "UTF-8")

point_nymph_complex <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "points_along_the_sacred_way/sw_point_nymphs.gml",
    sep = ""), layer = "sw_point_nymphs", encoding = "UTF-8")

point_panormos <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "points_along_the_sacred_way/panormos_port_point.gml",
    sep = ""), layer = "panormos_port_point",
    encoding = "UTF-8")

# optionally load survey point data from
# Lohmann's extensive survey of the Miletos
# Chora
lohmann_sites_file <- paste(working_dir, "gis-active-vector/archaeology
_base_features/lohmann_survey/",
    "sites_Lohmann.gml", sep = "")
if (file.exists(lohmann_sites_file)) {
    points_lohmann <- readOGR(dsn = lohmann_sites_file,
        layer = "sites_Lohmann", encoding = "UTF-8")
} else {
    points_lohmann <- NULL
}
```

Load relatively fixed ancient structures

```
outline_ancient_structures <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "points_along_the_sacred_way/ancient_structures.gml",
    sep = ""), layer = "ancient_structures", encoding = "UTF-8")
```

Load previous reconstructions and other useful contextual data

```
sacredway_schneider_south <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "schneider1987/sw_line_alt_Schneider.gml",
    sep = ""), layer = "sw_line_alt_Schneider",
    encoding = "UTF-8")
sacredway_schneider_north <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "schneider1987/sw_line_Schneider_MiletosSide.gml",
    sep = ""), layer = "sw_line_Schneider_MiletosSide",
    encoding = "UTF-8")
sacredway_wilski <- readOGR(dsn = paste(working_dir,
    "sacredway-data/sacred_way_reconstructions/",
    "wilski1907/sw_line_wilski_antikestrasse.gml",
    sep = ""), layer = "sw_line_wilski_antikestrasse",
    encoding = "UTF-8")
```

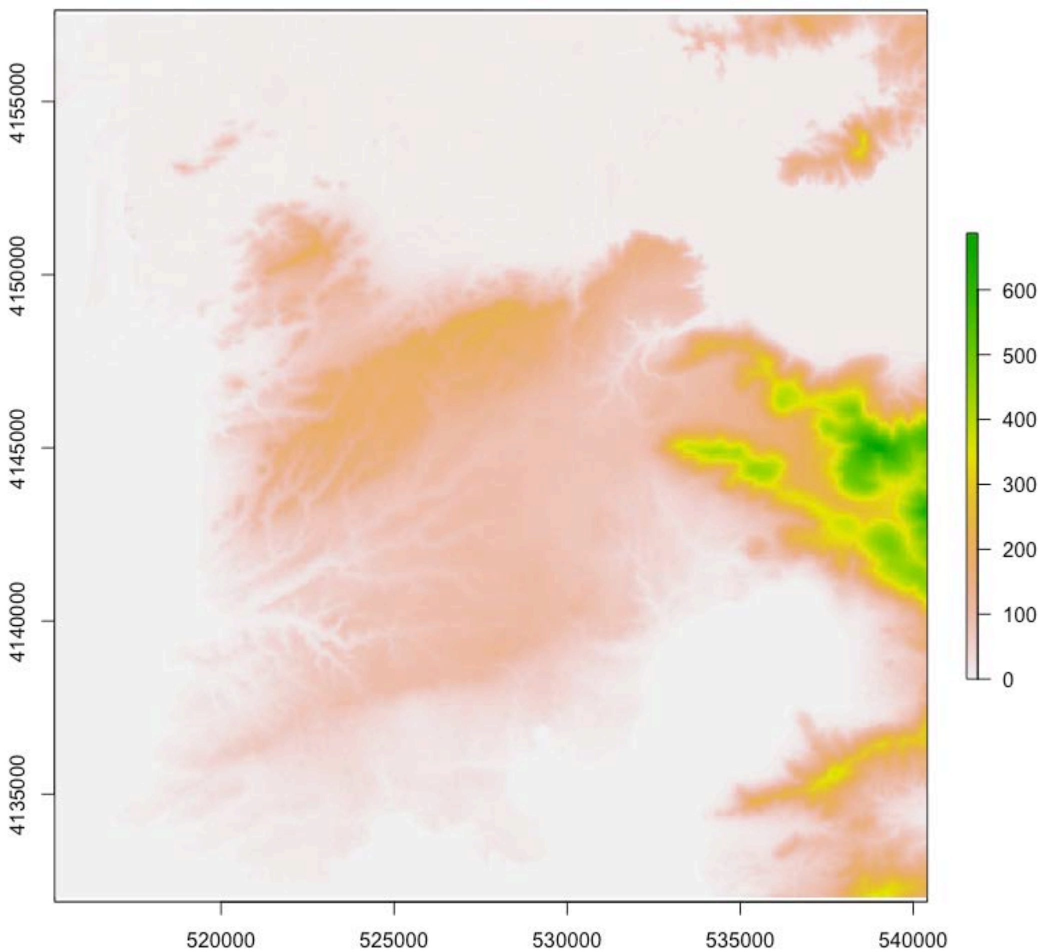
```
modern_major_roads <- readOGR(dsn = paste(working_dir,
    "gis-active-vector/modern_features/modern_roads/",
    "major_roads.gml", sep = ""), layer = "major_roads",
    encoding = "UTF-8")

wilski_paths <- readOGR(dsn = paste(working_dir,
    "gis-active-vector/modern_features/premodern_paths/",
    "wilski_paths.gml", sep = ""), layer = "wilski_paths",
    encoding = "UTF-8")
```

Load topographic models (DEMs)

The ASTER GDEM (Global Digital Elevation Model) is a product of METI and NASA.

```
# Needs to be changed to a standed DEM source,
# e.g. ASTER tile that anyone can download
# dem_modern <-
# raster(paste(working_dir,'gis-active-vector-raster/topography/',
# 'aster_based_dem/dem_asterN37E27_modern_20m.tif',
# sep = ''))

# Load from standard ASTER source.  Since the
# raw ASTER is distributed in LatLong
# projection, it needs to be
# reprojected/resampled to UTM to match the
# other parts of analysis, and cropped to a
# more managable area.
aster_file = paste(working_dir, "gis-static/dem/",
    "aster/ASTGTM2_N37E027/ASTGTM2_N37E027_dem.tif",
    sep = "")

if (file.exists(aster_file)) {
    dem_modern <- raster(aster_file)
} else {
    stop("You need to download the ASTER GDEM tile ASTGTM2_N37E027 into
/gis-static-dem/aster/ASTGTM2_N37E027/ before you can continue with thi
s analysis, or replace with your own DEM. Find in https://search.earthd
ata.nasa.gov/search .")
}

sr <- "+proj=utm +zone=35 +datum=WGS84 +units=m +no_defs"
dem_modern <- projectRaster(dem_modern, crs = sr)  # Reprojected to pro
ject coordinate system

## Crop just to area of wider Ionia crop area
## set using UTM co-ordinates cropbox
## <-c(501150,569930,4102950,4180970)
cropbox <- c(515200, 540400, 4132000, 4157500)  #4155000
dem_modern <- crop(dem_modern, cropbox)
```

```r
plot(dem_modern)

# dem_ancient is created programmatically from
# the modern dem
```




```r
# A hi-res dem derived by digitizing the
# contours in Paul Wilski's 1903 map of the
# peninsula
wilski_file <- paste(working_dir, "gis-active-raster/topography/",
    "wilski_dem/dem_wilskiso_landonly.tif", sep = "")

# If exists, load hires DEM, otherwise just
# use the standard DEM
if (file.exists(wilski_file)) {
    dem_wilski <- raster(wilski_file)
```

```
} else {
    dem_wilski <- dem_modern
}

# plot(dem_wilski)

# A polygon layer with the modern land shape
modern_land_shape <- readOGR(dsn = paste(working_dir,
    "sacredway-data/", "landshape/landshape_AD2000.gml",
    sep = ""), layer = "landshape_AD2000", encoding = "UTF-8",
    disambiguateFIDs = TRUE)

# Sea model according to Müllenhoff and
# Brückner
sea_inundation_800BC <- readOGR(dsn = paste(working_dir,
    "sacredway-data/", "landshape/sea_inundation_800BC.gml",
    sep = ""), layer = "sea_inundation_800BC",
    encoding = "UTF-8")

panormos_harbor_800BC <- readOGR(dsn = paste(working_dir,
    "sacredway-data/landshape/", "panormos_harbor_800BC.gml",
    sep = ""), layer = "panormos_harbor_800BC",
    encoding = "UTF-8")

meander_delta_800BC <- readOGR(dsn = paste(working_dir,
    "sacredway-data/landshape/", "meander_delta_800BC.gml",
    sep = ""), layer = "meander_delta_800BC",
    encoding = "UTF-8")

meander_delta_300BC <- readOGR(dsn = paste(working_dir,
    "sacredway-data/landshape/", "meander_delta_300BC.gml",
    sep = ""), layer = "meander_delta_300BC",
    encoding = "UTF-8")

meander_delta_1BC <- readOGR(dsn = paste(working_dir,
    "sacredway-data/landshape/", "meander_delta_1BC.gml",
    sep = ""), layer = "meander_delta_1BC", encoding = "UTF-8")

modern_baffa_golu <- readOGR(dsn = paste(working_dir,
    "sacredway-data/landshape/", "baffagolu.gml",
    sep = ""), layer = "baffagolu", encoding = "UTF-8")
```

Load multispectral imagery from worldview

```
multi_spectral_file <- paste(working_dir, "gis-static/imagery/",
    "worldview2/052720256010_01/052720256010_01_P001_MUL/",
    "11SEP04091901-M2AS-052720256010_01_P001.TIF",
    sep = "")

if (file.exists(multi_spectral_file)) {
```

```
    worldview_multi <- brick(multi_spectral_file)
    # transforms areas with value 0 to NA, i.e.
    # transparent or NoData
    worldview_multi[worldview_multi == 0] <- NA
} else {
    worldview_multi <- NULL
    warning("No satellite imagery present. Will be unable to plot World
View-2 basemap")
}
```

TRANSFORM LAND-SHAPE AND DEM DATA

Create land-shape vectors

The ancient land-shapes are calculated by "cutting out" those areas of the modern land-shape which were sea in the past.

```
# Fix potential invalid geometries with
# 0-width buffer (i.e. self-intersections)
modern_land_shape <- gBuffer(modern_land_shape,
    byid = TRUE, width = 0)
sea_inundation_800BC <- gBuffer(sea_inundation_800BC,
    byid = TRUE, width = 0)
panormos_harbor_800BC <- gBuffer(panormos_harbor_800BC,
    byid = TRUE, width = 0)

ancient_land_shape_800BC <- gDifference(modern_land_shape,
    sea_inundation_800BC, byid = TRUE)
# take account of the additional area around
# Panormos which may have been sea rather than
# land
ancient_land_shape_800BC_panormos <- gDifference(ancient_land_shape_800
BC,
    panormos_harbor_800BC, byid = TRUE)
```

Extract values for modern and ancient land-shapes from DEM rasters

Only the values from areas which were deemed to be land at certain dates should be included in the travel-distance calculations. To do this, the vector footprints of the land-shape at certain times are used to extract only these values.

```
# define function to clip a raster by a
# polygon shapefile
cliprasterbypolygon <- function(r, f, i = FALSE) {
    # only works if r (raster) and f (vector) are
    # in the same projection based on code answer
    # from Jeffrey Evans:
    # http://gis.stackexchange.com/questions/92221/
    # cr <- crop(r, extent(f), snap='in')
```

```
    cr <- r
    fr <- rasterize(f, cr)
    # plot(fr) plot(f, add=TRUE)
    lr <- mask(x = cr, mask = fr, inverse = i)
    return(lr)
}

dem_ancient <- cliprasterbypolygon(dem_modern,
    ancient_land_shape_800BC)
dem_modern <- cliprasterbypolygon(dem_modern,
    modern_land_shape)
# additional step required to ensure the Baffa
# Golu is indeed modelled as water (i.e. NA)
dem_modern <- cliprasterbypolygon(dem_modern,
    modern_baffa_golu, i = TRUE)


#### full wilski dem is very large (high res), so
#### only use the full version when ready to wait
#### dem_wilski_modern <- dem_wilski
#### dem_wilski_ancient <-
#### cliprasterbypolygon(dem_wilski,ancient_land_shape_800BC)
#### dem_wilski_prealluv <-
#### cliprasterbypolygon(dem_wilski,ancient_land_shape_800BC_panormos)

#### for now use stand-ins
dem_wilski_modern <- dem_modern
dem_wilski_ancient <- dem_ancient
dem_wilski_prealluv <- cliprasterbypolygon(dem_ancient,
    ancient_land_shape_800BC_panormos)
```

Crop DEM to area of interest for this analysis only

Only a discrete part of the DEM models is needed and to save processing time analysis and plots to the Milesian peninsula. The cropped area is hard-coded as `cropbox` below in UTM coordinates.

A second crop restricts the higher-resolution Wilksi-based DEM to a smaller area between Akkron and Didyma

```
## Whole peninsula crop area set using UTM
## co-ordinates
cropbox <- c(515200, 540400, 4132000, 4155000)

dem_modern <- crop(dem_modern, cropbox)
dem_ancient <- crop(dem_ancient, cropbox)

## Panormos close-up crop area set using UTM
## co-ordinates
```

```
panormos_cropbox <- c(518050, 527880, 4136500,
    4145500)
dem_wilski_modern <- crop(dem_wilski_modern, panormos_cropbox)
dem_wilski_ancient <- crop(dem_wilski_ancient,
    panormos_cropbox)
dem_wilski_prealluv <- crop(dem_wilski_prealluv,
    panormos_cropbox)
```

Export geographical data into re-usable GeoTIFF format (optionally)

```
# Export dem to packages
# writeRaster(dem_modern,
# filename=paste(export_dir,'dem_modern.tif',sep=''),
# overwrite=TRUE) writeRaster(dem_ancient,
# filename=paste(export_dir,'dem_ancient.tif',sep=''),
# overwrite=TRUE)
# writeRaster(dem_wilski_ancient,
# filename=paste(export_dir,'dem_wilski_ancient.tif',sep=''),
# overwrite=TRUE)
# writeRaster(dem_wilski_prealluv,
# filename=paste(export_dir,'dem_wilski_prealluv.tif',sep=''),
# overwrite=TRUE)
```

LOCATING THE STUDY AREA

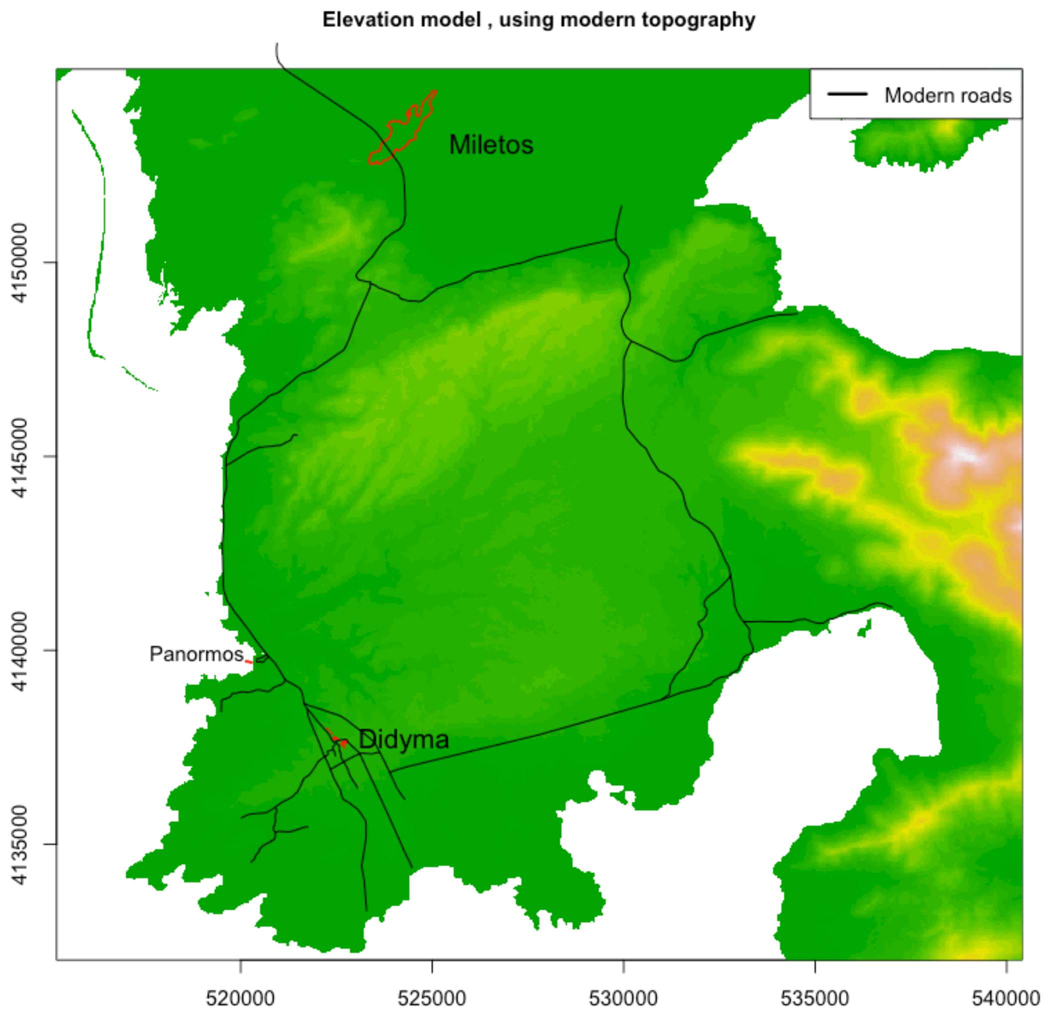
GENERAL LOCATION OF ANALYSIS

Location of the Milesian Peninsula: Miletos, Didyma, and Panormos and changing topography

The Milesian peninsula is located on the west coast of modern Turkey, facing the Aegean sea. Today, the peninsula appears part of the mainland Turkish landmass, as a result of the extensive infilling of the former bay of Miletos by the alluvial delta created by sediment carried by the river Meander (modern Turkish Menderes or ancient Meandros).

```
sw_general_map <- function(dem, map_suffix="", roads="yes"){
  # Plot the background raster
  par(oma = c(0,0,0,0), xpd = TRUE)

  # Plot the basic terrain model
  col.palette = terrain.colors(30)
  image(dem,
        col = col.palette,
        xlab = "",
        ylab = ""
  )

  plot(outline_ancient_structures,
```

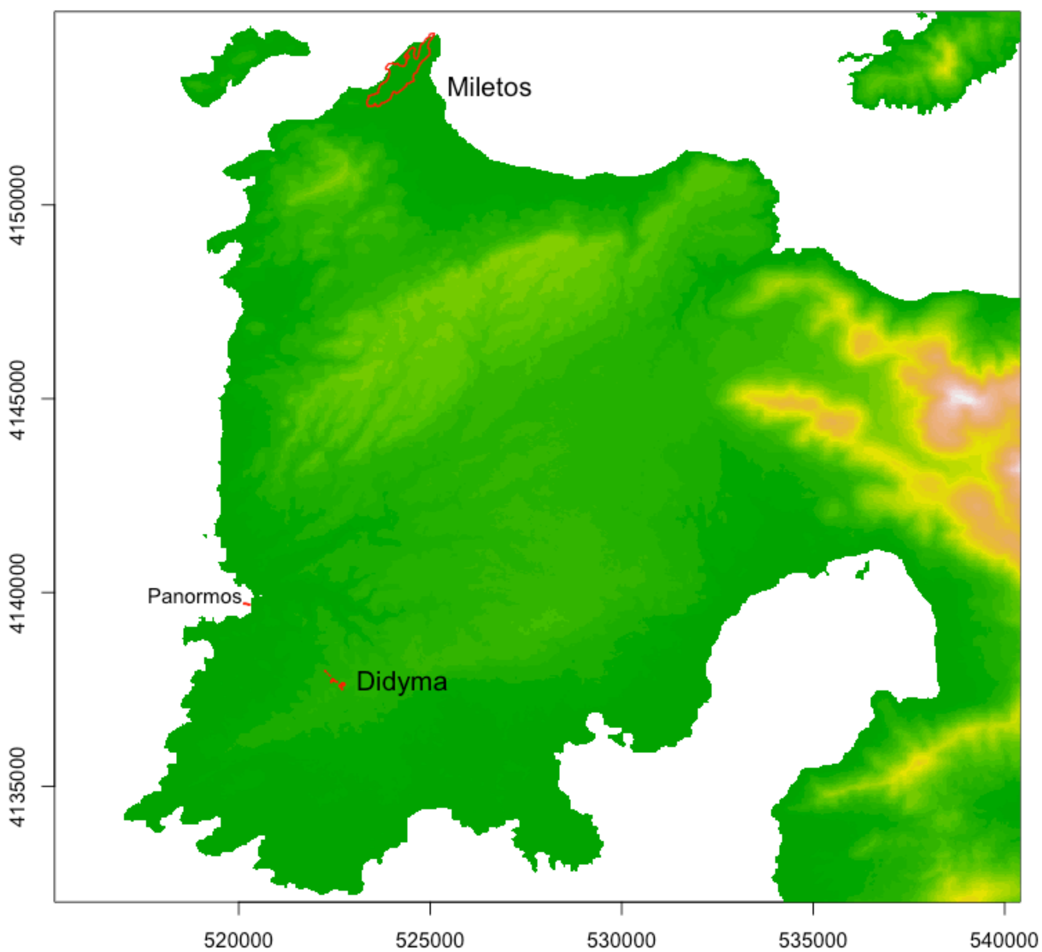
```r
       border = "red",
       col = "transparent",
       lty = 1,
       lwd = 1.4,
       add = T
  )

  if (roads=="yes") plot(modern_major_roads,
       border = "black",
       col = "black",
       lty = 1,
       lwd = 1.1,
       alpha = 0.8,
       add = T
  )

  # Point text labels
  # pos=4 is to the right, 2=L, 1=below, 3=above
  text(coordinates(point_didyma_altar)[,1],
       coordinates(point_didyma_altar)[,2], "Didyma",
       pos= 4, offset=0.5, col="black", cex=1.3)
  text(coordinates(point_sacred_gate)[,1],
       coordinates(point_sacred_gate)[,2], "Miletos",
       pos= 4, offset=1.8, col="black", cex=1.3)
  text(coordinates(point_panormos)[,1],
       coordinates(point_panormos)[,2], "Panormos",
       pos= 2, offset=0.8, col="black", cex=1)

  if (roads=="yes")
  {
    legend("topright", # places a legend
         c("Modern roads"), # puts text in the legend
         lty=c(1), # appropriate symbols (lines)
         lwd=c(2.5),
         col=c("black"), # lines the correct color and width
         bg="white",
         box.col="black"
    )
  }

  # Title
  title(main=paste("Elevation model",map_suffix),
        outer = FALSE,
        cex.main = 1
  )
}

# Plot the map using cropped version of modern topography
sw_general_map(dem_modern, map_suffix=", using modern topography")
```



Up until sometime in the Late Antique or Early Medieval period, however, the peninsula was only connected to the mainland via a relatively thin and mountainous strip in the south-east of the region. For this reason, the Milesian peninsula was, in ancient times, a true semi-island with most outside connections probably conducted by sea.

```
# Plot the map using cropped version of
# ancient topography
sw_general_map(dem_ancient, map_suffix = ", using ancient topography",
    roads = "no")
```

Elevation model , using ancient topography



Within the *half-island*, settlements were presumably connected together with various internal tracks and roads, whether for driving animals, transporting goods or, as in the case of the Sacred Way, connecting important religious locales across Milesia.

Reconstructions of the route of the Sacred Way

A proposed reconstruction of the entire route of the Sacred Way was published by Peter Schneider (1987) and has become the orthodox theory. Earlier, however, the coastal road was also assumed to be the most likely route, although Paul Wilski identified an ancient street running inland through the Akron hills.

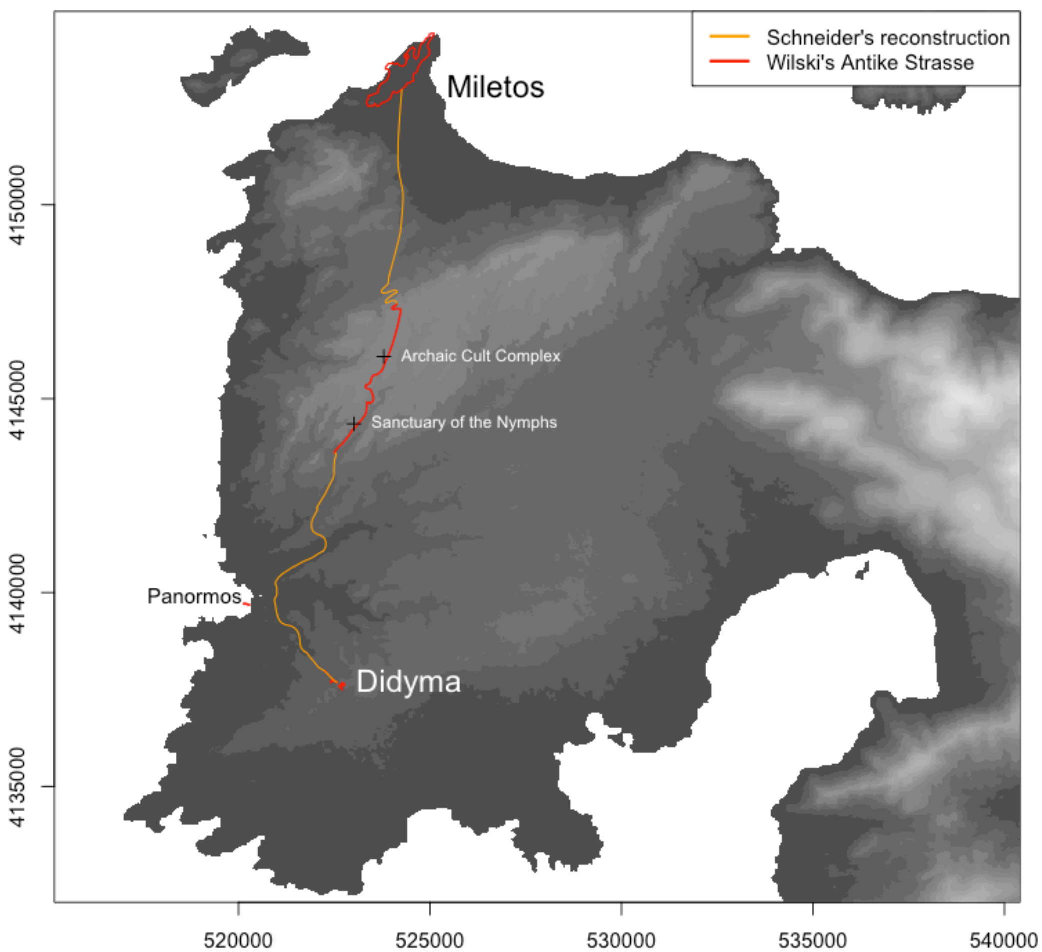
The orthodox route of the Sacred Way

```
sw_general_place_labels <- function(place_lists = "DMPCN") {
    # A function to simplify the points labelled
    # by text in each map pos=4 is to the right,
    # 2=L, 1=below, 3=above
```

```
    if (grepl("D", place_lists)) {
        text(coordinates(point_didyma_altar)[,
            1], coordinates(point_didyma_altar)[,
            2], "Didyma", pos = 4, offset = 0.5,
            col = "white", cex = 1.5)
    }
    if (grepl("M", place_lists)) {
        text(coordinates(point_sacred_gate)[,
            1], coordinates(point_sacred_gate)[,
            2], "Miletos", pos = 4, offset = 1.8,
            col = "black", cex = 1.5)
    }
    if (grepl("P", place_lists)) {
        text(coordinates(point_panormos)[, 1],
            coordinates(point_panormos)[, 2],
            "Panormos", pos = 2, offset = 0.8,
            col = "black", cex = 1)
    }
    if (grepl("C", place_lists)) {
        text(coordinates(point_cult_complex)[,
            1], coordinates(point_cult_complex)[,
            2], "Archaic Cult Complex", pos = 4,
            offset = 0.7, col = "white", cex = 0.8)
    }
    if (grepl("N", place_lists)) {
        text(coordinates(point_nymph_complex)[,
            1], coordinates(point_nymph_complex)[,
            2], "Sanctuary of the Nymphs", pos = 4,
            offset = 0.7, col = "white", cex = 0.8)
    }
}

sw_general_reconstructions <- function(working_dem,
    primary_col = "orange", secondary_col = "red") {
    # Plot the background raster
    par(oma = c(0, 0, 0, 0), xpd = TRUE)

    # Plot the basic terrain model
    image(working_dem, col = gray.colors(20),
        xlab = "", ylab = "")

    plot(outline_ancient_structures, border = "red",
        col = "transparent", lty = 1, lwd = 1.3,
        add = T)

    plot(sacredway_schneider_south, col = primary_col,
        lty = 1, lwd = 1.1, add = T)
    plot(sacredway_schneider_north, col = primary_col,
        lty = 1, lwd = 1.1, add = T)
```

```
    plot(sacredway_wilski, col = secondary_col,
        lty = 1, lwd = 1.5, add = T)

    # Plot additional sites along the way
    plot(point_cult_complex, border = "black",
        add = T)
    plot(point_nymph_complex, border = "black",
        add = T)

    # Point text labels
    sw_general_place_labels()

    legend("topright", c("Schneider's reconstruction",
        "Wilski's Antike Strasse"), lty = c(1,
        1), lwd = c(2.5, 2.5), col = c("orange",
        "red"), bg = "white", box.col = "black")

    # Title
    title(main = paste("Reconstructed route of the sacred way"),
        outer = FALSE, cex.main = 1)
}

# Plot previous reconstructions with modern
# dem and default colours
sw_general_reconstructions(dem_ancient)
```

Reconstructed route of the sacred way




```
# A general settings for plotting maps for the rest of the analysis
sw_plot_map <- function(dem=NULL, overlay=NULL, col=NA,
      colNA=NA, alpha=1, legend=TRUE, title="",
      lohmann="", worldview="") {
  # Plot the background raster
  par(oma = c(0,0,0,0), xpd = TRUE)

  ## nb: it may be better to re-do this using spplot or
  ## ggplot in order to add more control and avoid axis/aspect
  ## issues with the spatial layers

  # Plot the basic terrain model
  if (!is.null(dem)) plot(dem,
       col = gray.colors(20),
       alpha = 0.6,
       legend = FALSE
```

```
      #yaxt="n",
      #xaxt="n"
  )

  # Plot satellite image if relevant
  if (worldview=="yes" && !is.null(worldview_multi)) {
    plotRGB(worldview_multi, r=5, g=3, b=2, stretch="lin", add=T)
  }

  # Plot the overlay (add if there is a dem, otherwise just plot direct
)
  if (!is.null(overlay) && !is.null(dem)) plot(overlay,
      col = col,
      colNA = colNA,
      alpha = alpha,
      add = T
  )
  if (!is.null(overlay) && is.null(dem)) plot(overlay,
      col = col,
      colNA = colNA,
      alpha = alpha
  )

  plot(outline_ancient_structures,
      border = "red",
      col = "transparent",
      lty = 1,
      lwd = 1.3,
      add = T
  )

  # Plot the 'orthodox' routes as comparison
  plot(sacredway_schneider_south,
      col = "black",
      lty = 3,
      lwd = 0.9,
      add = T
  )
  plot(sacredway_schneider_north,
      col = "black",
      lty = 3,
      lwd = 0.9,
      add = T
  )
  plot(sacredway_wilski,
      col = "black",
      lty = 6,
      lwd = 1.1,
      add = T
```

```
)

if (lohmann=="yes") {
  points_subset <- crop(points_lohmann,dem)
  points_datedsubset <- subset(points_subset,
         (grepl("HEL", points_subset$Dating) |
          grepl("CLA", points_subset$Dating) |
          grepl("ROM", points_subset$Dating) |
          grepl("ARC", points_subset$Dating)) )
  plot(points_datedsubset,
     col = "red", # 36=a dark blue
     pch = 3,
     cex = 0.6,
     alpha = 0.7,
     add = T
  )
}

# Point text labels
# pos=4 is to the right, 2=L, 1=below, 3=above
text(coordinates(point_didyma_altar)[,1],
     coordinates(point_didyma_altar)[,2], "Didyma",
     pos= 4, offset=0.5, col="white", cex=1.5)
text(coordinates(point_sacred_gate)[,1],
     coordinates(point_sacred_gate)[,2], "Miletos",
     pos= 4, offset=1.8, col="black", cex=1.5)
text(coordinates(point_panormos)[,1],
     coordinates(point_panormos)[,2], "Panormos",
     pos= 2, offset=0.9, col="black", cex=1)

# Axes
#axis(2, hadj=0, col="red", cex=0.6) # left (north) axis
#axis(1, hadj=0, col="red", cex=0.6) # bottom (east) axis

# Legend text (just the orthodox route, plus ancient structures)
legend("topright", # location
       c("Orthodox reconstruction","Ancient structures"), # legend
       lty=c(3,1), # symbols (lines)
       pch=c(NA,0), # symbols (over the line)
       lwd=c(1,1.3), # line width
       col=c("black","red"), # color and width
       bg="white",
       box.col="black"
)
txtkey <- c(paste("Sites recorded in Lohmann's ",
                  "extensive survey as Archaic, ",
                  "Classical, Hellenistic or ",
                  "Roman",sep=""))
if (lohmann=="yes") {
```

```
    legend("bottomright",txtkey, pch=c(3),
           col=c("red"), cex=c(0.7),
           bg="white", box.col="black")
  }

  txtkey <- c("Base-map: Worldview-2 satellite image, ",
              "4 Sep 2011")
  if (worldview=="yes" && !is.null(worldview_multi)) {
    legend("topleft",txtkey,
           pch=c(3), col=c("white"),
           cex=c(0.6), bg="white", box.col="black")
  }

  # Title
  title(main=title,
        outer = FALSE,
        cex.main = 1,
        xlab = "east (UTM 36N)",
        ylab = "north"
  )
}
```

Explaining the analyses in geographical context

Create a conductance model (i.e., the inverse of a cost/friction/resistance surface)

Before any cost/friction-based analyses can be made, a model must be established to enable subsequent calculations. The library used to make these calculations (`gdistance`) relies on a conductance model (effectively the inverse of a cost/friction/resistance model) in order to efficiently store the same network of relationships between cells. For the purposes of the rest of this section, the phrase "resistance" will be used as equivalent to cost or friction in the sense of travel resistance across a geographical surface.

A varied and complex set of variables could theoretically be included in resistance-based models, depending on purpose of the analysis, but in this case, we are primarily interested in the effects of landscape change on the dominant factor in route creation (topography). In this work, then, topography (or rather slope) is used as the only variable to contribute to resistance.

The initial analysis for this study was conducted using ArcGIS's PathDistance tool and the procedures presented here were originally an attempt to replicate the same workflow. Note, however, that differences in the way that PathDistance and gdistance are implemented means that results are likely not to be identical. Whereas PathDistance uses a formula based on a cost-raster (and then uses elevation values and any additional vertical or horizontal factors) to multiply the resistence, gdistance relies on a `transitionFunction` to create a conductance network. This `transitionFunction` must be manually designed by the user. This means that anisotropic aspects (such as the additional distance travelled vertically across a slope, and the variation in time/effort required to climb or descend a slope) must be additionally programmed in.

A helpful example on how to use the `gdistance` package for modeling movement across a terrain is provided under "Example 1: Hiking around Maunga Whau" in the `gdistance` package introductory vignette by Jacob van Etten (2014), *R Package gdistance: Distances and Routes on Geographical Grids*. Adaptation to this workflow were needed, however, for the fact that the analysis described in the current paper includes an area of sea (recorded as `NoData` or `NA`). More details on the workings of `gdistance` can be found from the package documentation (link to CRAN: https://cran.r-project.org/web/packages/gdistance/index.html).

Additionally, it is worth examining the discussion and review of least-cost procedures for archaeological applications in Irmela Herzog's theoretical articles (e.g., Herzog 2013a, 2013b). She offers a range of alternative models that, while not applied here, could offer alternative interpretative opportunities, including a model which is based on physiological experiments.

Transform elevation to slope: simple slope-as-resistance model

The simplest and often adequate initial model for resistance (or its inverse conductance) is based upon the slope of terrain.

Since slope by itself is not directly proportional to real-world costs (e.g., energy expenditure while walking, or time taken to walk up or down a given slope), various models have been proposed which are designed to provide more realistic or, often, more intuitive results to resistance-based analyses. The model presented here uses the "correction function" used by Bell et al. (2002).

This simple model is flawed in certain details: first it is symmetrical, in that upslope and downslope are given equal weight (which is physiologically untrue), and second it is isotropic, in that it does not take account of the additional distance which must be covered by travelling vertically across the slope, as opposed to travelling horizontally across a flat terrain.

The second factor is likely to exaggerate the effects of slope through multiplication. The first may have a more "flattening" effect for relatively gentle slopes for shortest paths (although it may have less effect on symmetrical analysis such as cost-corridors).

However, though testing is required, and the individual paths or corridors created might differ, it is unlikely the core results presented in this particular analysis would be radically different.

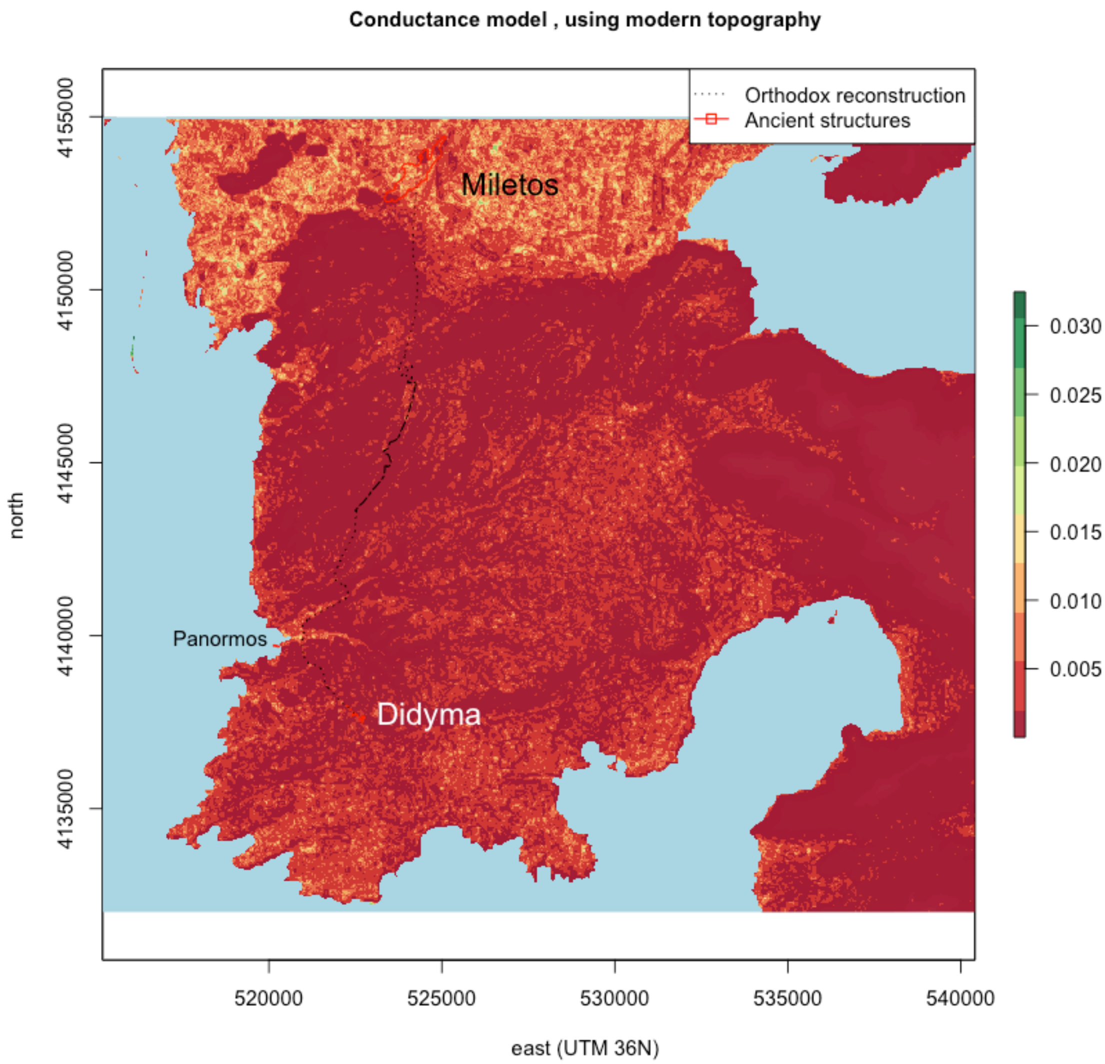
```
sw_simple_slope_conductance <- function(dem, dirs = 16,
    symm = FALSE) {
    # find slope
    slope <- terrain(dem, opt = "slope", unit = "radians",
        neighbors = 8)
    # slope <- tan(slope) * 100 # convert to
```

```
    # percent slope can be treated as a basic cost
    # but slope on its own is problematic, hence
    # the conversion formula, provided by Bell et
    slope <- tan(slope)/tan(pi/180)
    # gdistance requires a conductance (i.e.
    # 1/cost), but Inf conductance is problematic,
    # hence the +1
    slope <- (1/(1 + slope))
    # areas which are NA (e.g. the sea) should be
    # modelled as 0 conductance (Inf cost)
    slope[is.na(slope)] <- 0
    # the transition function sets the manner in
    # which cost is calculated between two
    # adjacent cells x[1] and x[2]
    tF <- function(x) {
        x[1] * x[2]
    }
    tr <- transition(slope, transitionFunction = tF,
        directions = dirs, symm = symm)
    # divide by the distance between cells
    tr <- geoCorrection(tr, type = "c")
    return(tr)
}

# Set alias to select which conductance
# function to use
sw_conductance <- function(dem, dirs = 16, symm = FALSE) {
    sw_simple_slope_conductance(dem, dirs = dirs,
        symm = symm)
}
```

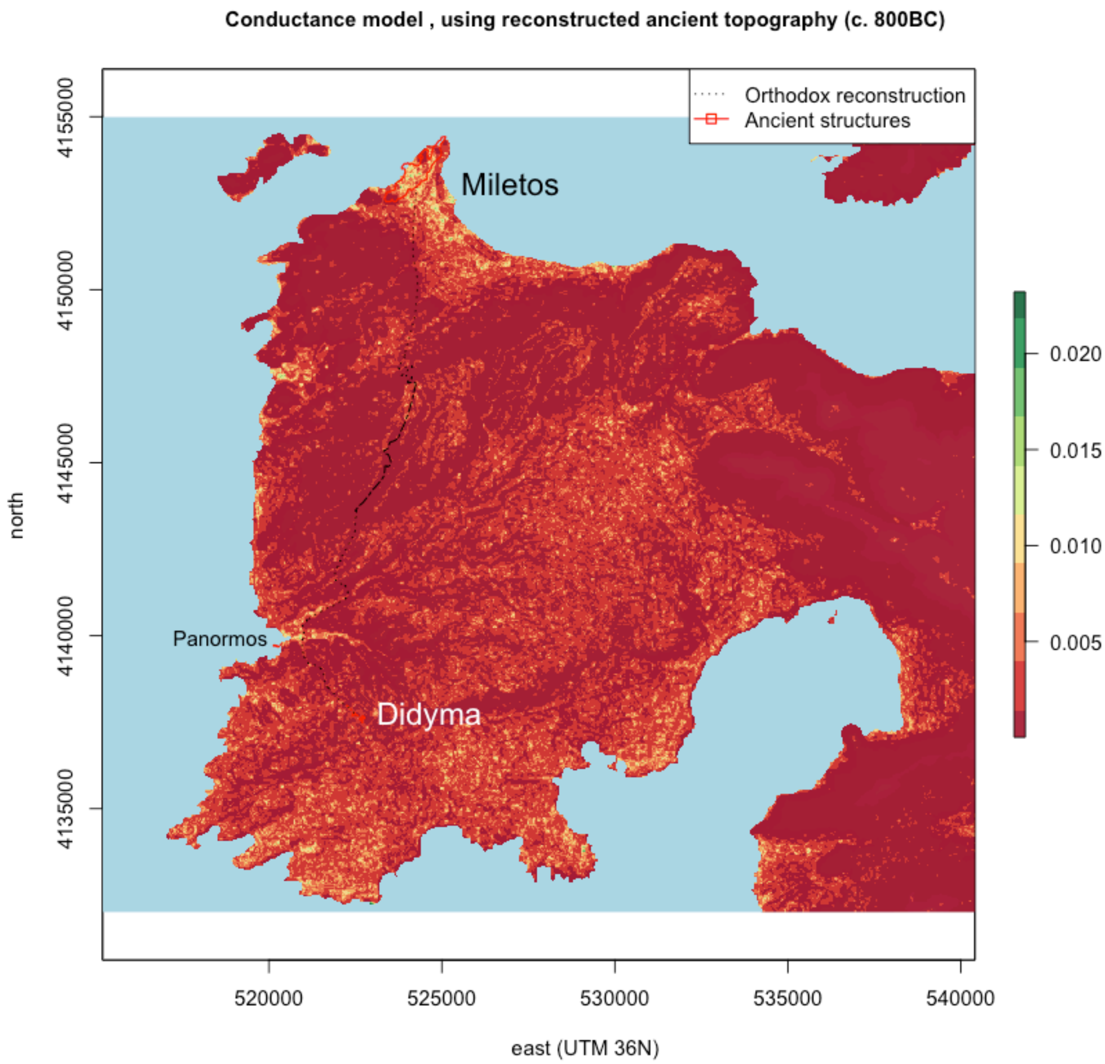
Such relative conductance models can be visualized as a raster map geographically:

```
sw_plot_conductance <- function(dem, conductance,
    map_suffix = "") {
    # Create colour palette and plot
    col.palette <- brewer.pal(10, "RdYlGn")
    sw_plot_map(dem, overlay = raster(conductance),
        col = col.palette, colNA = "lightblue",
        alpha = 0.9, title = paste("Conductance model",
            map_suffix))
}

# create sample symmetrical conductance using
# modern topography and plot as map
conductance_symm_mod <- sw_conductance(dem_modern,
    dirs = 16, symm = TRUE)
sw_plot_conductance(dem_modern, conductance_symm_mod,
    ", using modern topography")
```

```
# create sample symmetrical conductance using
# ancient topography and plot as map
conductance_symm_anc <- sw_conductance(dem_ancient,
    dirs = 16, symm = TRUE)
sw_plot_conductance(dem_ancient, conductance_symm_anc,
    ", using reconstructed ancient topography (c. 800BC)")

# other types of plot for testing purposes
# conductance_symm_mod
# image(transitionMatrix(conductance_symm_mod))
# conductance_symm_anc
```



Conductance model , using modern topography
Orthodox reconstruction
Ancient structures
Miletos
Panormos
Didyma
north
4155000
4150000
4145000
4140000
4135000
520000
525000
530000
535000
540000
east (UTM 36N)
0.030
0.025
0.020
0.015
0.010
0.005



This `conductance` matrix can now be used to perform various distance calculations using `gdistance` functions.

CREATE SHORTEST PATHS BETWEEN TWO POINTS: MILETOS AND DIDYMA

Establishing the shortest path (often known as a least-cost-path) is perhaps the most common application of cost-surface techniques. It presents a single optimum calculation of the route with the lowest cumulated cost (or highest conductance), using a step-by-step algorithm to reach a particular destination point from a particular source point.

The `shortestPath` algorithm in the `gdistance` library uses Dijkstra's algorithm (Dijkstra 1959). Additionally, the path from A to B is usually not identical to the path from B to A, because of the asymmetry of the model and the algorithm used.

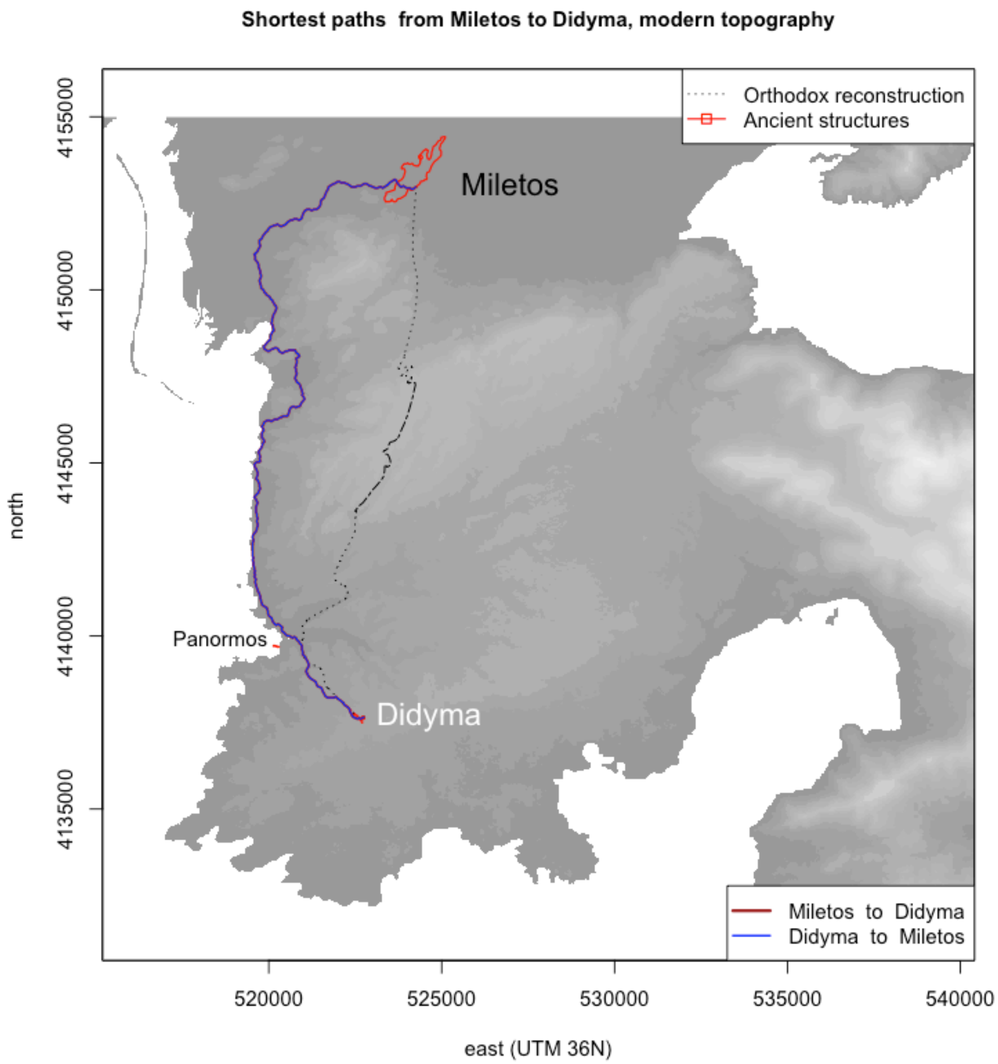
Here the shortest path from the so-called Sacred Gate complex at Miletos (the presumed start of the Sacred Way as it left the city walls) to the altar in front of the Temple of Apollo at Didyma is calculated as well as its inverse.

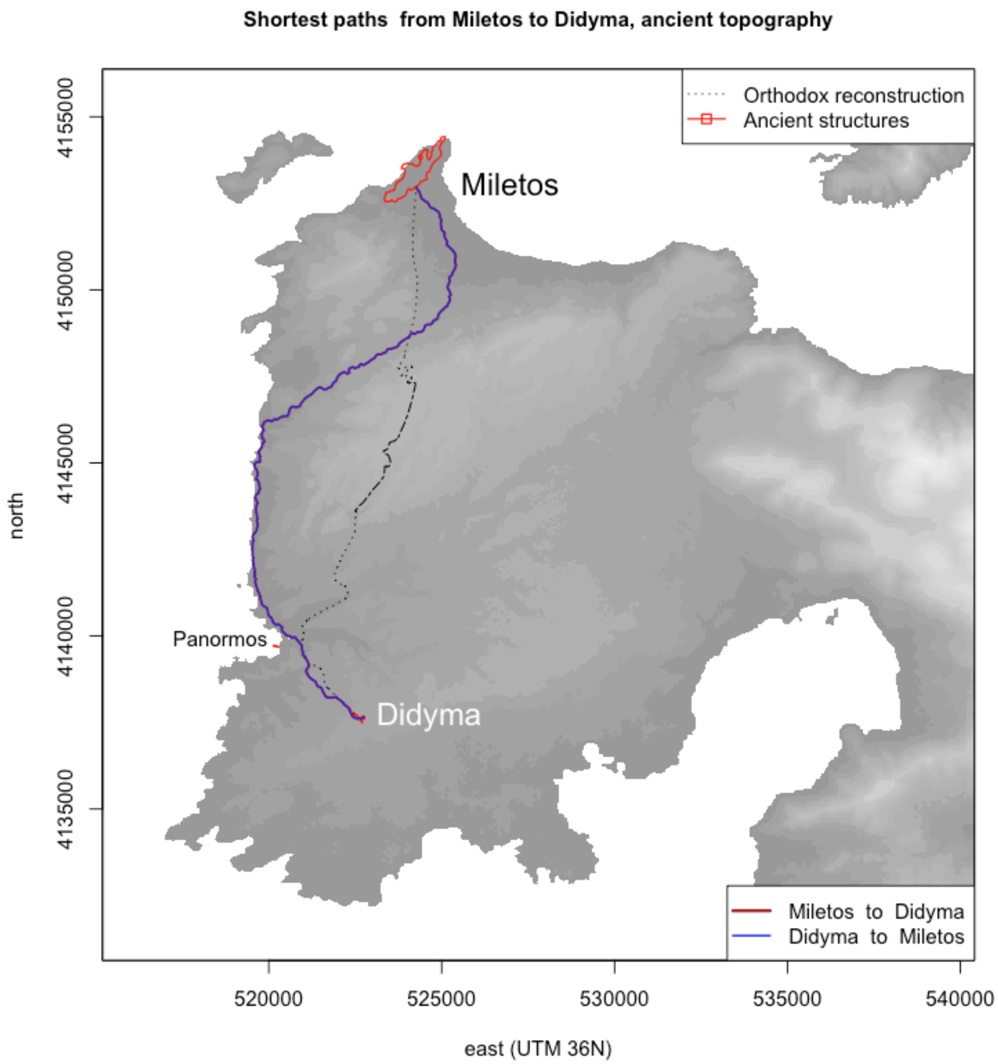
```
## using modern topography create assymetrical
## conductance transition
conductance_mod <- sw_conductance(dem_modern,
    dirs = 16, symm = FALSE)
# plot assymetric conductance (testing only)
# sw_plot_conductance(dem_modern,
# conductance_mod, ', using reconstructed
# modern topography')

# shortest path and its inverse
shortestpathMtoD_mod <- shortestPath(conductance_mod,
    point_sacred_gate, point_didyma_altar, output = "SpatialLines")
shortestpathDtoM_mod <- shortestPath(conductance_mod,
    point_didyma_altar, point_sacred_gate, output = "SpatialLines")

## using ancient topography create assymetrical
## conductance transition
conductance_anc <- sw_conductance(dem_ancient,
    dirs = 16, symm = FALSE)
# shortest path and its inverse
shortestpathMtoD_anc <- shortestPath(conductance_anc,
    point_sacred_gate, point_didyma_altar, output = "SpatialLines")
shortestpathDtoM_anc <- shortestPath(conductance_anc,
    point_didyma_altar, point_sacred_gate, output = "SpatialLines")
```

The geographical footprint of these shortest paths appears as follows:

```
sw_plot_shortestpathpair <- function(dem, sp1,
    sp2, map_suffix = "", sp1_text = "A", sp2_text = "B") {
    sw_plot_map(dem, title = paste("Shortest paths",
        map_suffix))

    # Plot the two shorted (least-cost) paths
    plot(sp1, col = "brown", lty = "solid", lwd = 2,
        add = T)
    plot(sp2, col = "blue", lty = "solid", lwd = 1,
        add = T)

    # Legend text
    legend("bottomright", c(paste(sp1_text, " to ",
        sp2_text), paste(sp2_text, " to ", sp1_text)),
        lty = c(1, 1), pch = c(NA, NA), lwd = c(2.5,
            1.5), col = c("brown", "blue"), bg = "white",
        box.col = "black")
```

```
    # Label ends of lines? [WIP]!
    # text(coordinates(sp1)[,1],
    # coordinates(sp1)[,2], sp1_text)
    # text(coordinates(sp2)[,1],
    # coordinates(sp2)[,2], sp2_text)
}

sw_plot_shortestpathpair(dem_modern, shortestpathMtoD_mod,
    shortestpathDtoM_mod, " from Miletos to Didyma, modern topography",
    sp1_text = "Miletos", sp2_text = "Didyma")
sw_plot_shortestpathpair(dem_ancient, shortestpathMtoD_anc,
    shortestpathDtoM_anc, " from Miletos to Didyma, ancient topography"
,
    sp1_text = "Miletos", sp2_text = "Didyma")
```


Shortest paths from Miletos to Didyma, modern topography
Orthodox reconstruction
Ancient structures
Miletos
Panormos
Didyma
Miletos to Didyma
Didyma to Miletos
north
4155000
4150000
4145000
4140000
4135000
520000
525000
530000
535000
540000
east (UTM 36N)



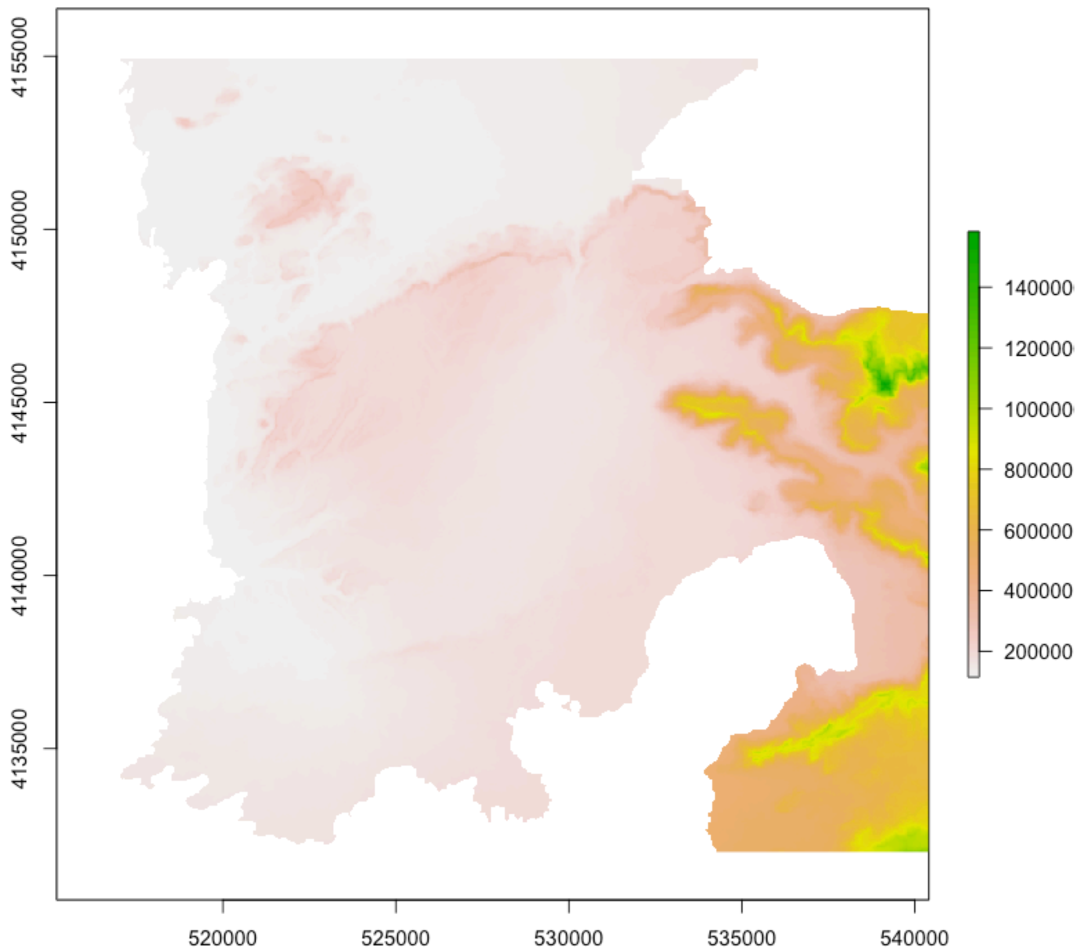
Create cost-corridor probability surface: Miletos to Didyma

Unitary least-cost-paths are problematic in as much as they represent arbitrary single routes and do not give any sense of long-term variation. Alternative models providing a range of probabilities have therefore been suggested, including cost corridors (normally the sum of two accumulated-cost-distance surfaces, in `gdistance` this is called `accCost`) and, where there are more than two-nodes involved, circuit-based modeling or resistance modeling (which in the case of `gdistance` is called `commuteDistance`).

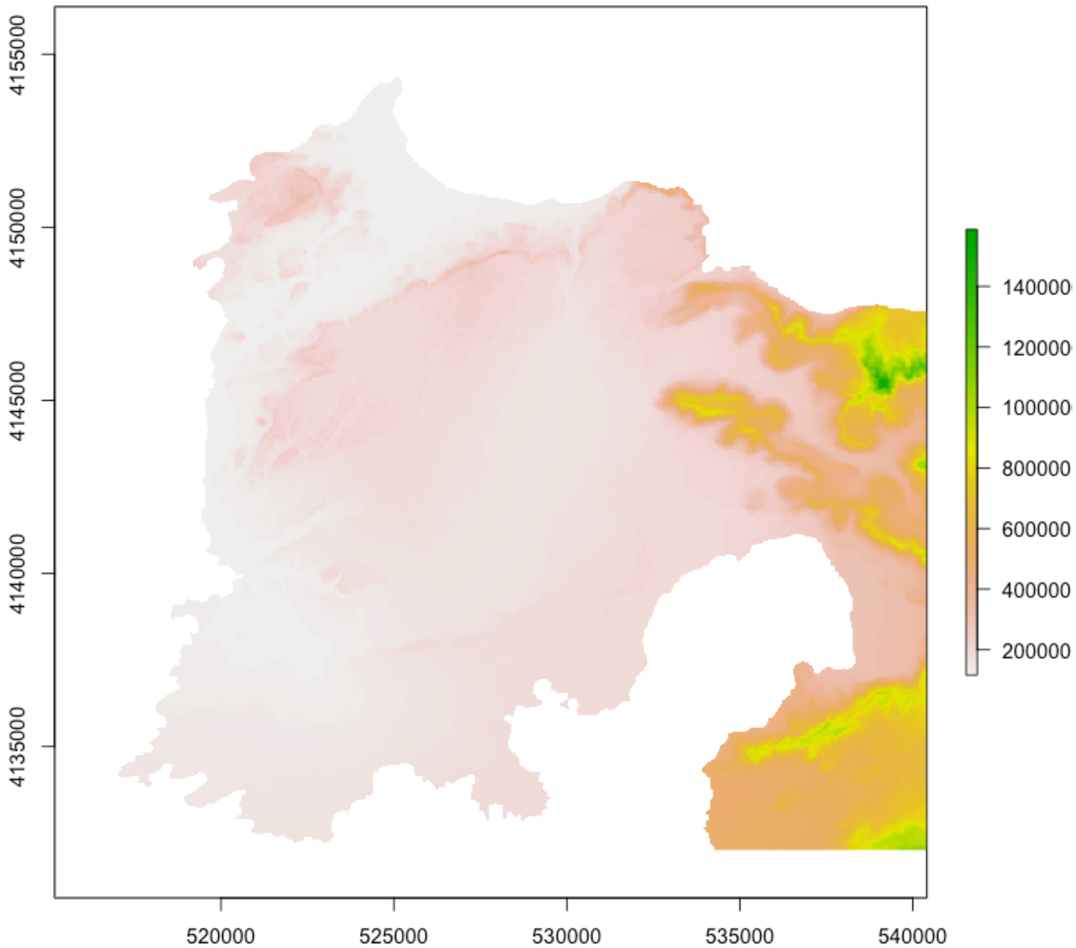
Creating a cost corridor between two points simply involves the sum or average of two accumulated cost surface calculations, one from each point.

```
sw_costcorridor <- function(conductance_symm,
    p1, p2) {
```

```r
    accCostDistanceFromP1 <- accCost(conductance_symm,
        p1)
    accCostDistanceFromP2 <- accCost(conductance_symm,
        p2)

    # add the two cost distances together
    return(accCostDistanceFromP1 + accCostDistanceFromP2)
}

# modern
costCorridorBetweenMandD_mod <- sw_costcorridor(conductance_symm_mod,
    point_sacred_gate, point_didyma_altar)
# costCorridorBetweenMandD_mod
plot(costCorridorBetweenMandD_mod)

# ancient meander
costCorridorBetweenMandD_anc <- sw_costcorridor(conductance_symm_anc,
    point_sacred_gate, point_didyma_altar)
# costCorridorBetweenMandD_anc
plot(costCorridorBetweenMandD_anc)
```



4155000
4150000
4145000
4140000
4135000
520000
525000
530000
535000
540000
140000
120000
100000
800000
600000
400000
200000



The resultant raster needs to be reclassified in order to visualize corridors and exclude areas not of interest, for example, as follows:

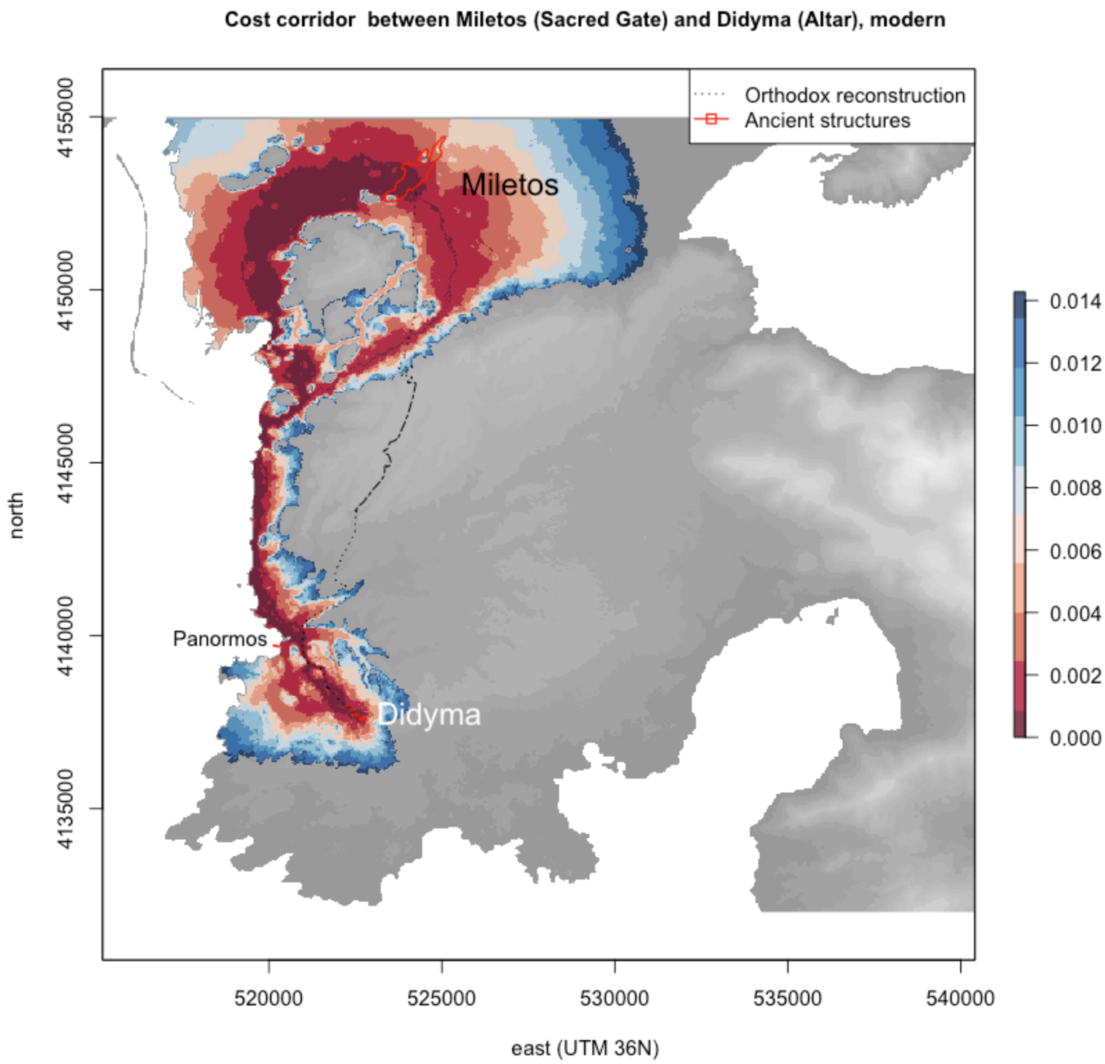
```
sw_costcorridor_scale <- function(conductance_symm,
    p1, p2, rescale = TRUE, max = 1, percentile = 1) {
    accCostDistanceFromP1 <- accCost(conductance_symm,
        p1)
    accCostDistanceFromP2 <- accCost(conductance_symm,
        p2)

    # add the two cost distances together
    costCorridor = accCostDistanceFromP1 + accCostDistanceFromP2

    # first need to exclude Inf accumulate cost by
    # setting to NA
    costCorridor[is.infinite(costCorridor)] = NA
```

```
    # function to rescale cell values between 0
    # and 1 from Tim Assal
    # http://www.timassal.com/?p=859
    rasterRescale <- function(r) {
        ((r - cellStats(r, "min"))/(cellStats(r,
            "max") - cellStats(r, "min")))
    }

    # rescale to between 0 and 1 if rescale set to
    # TRUE
    costCorridor_reclass <- costCorridor
    if (rescale)
        costCorridor_reclass <- rasterRescale(costCorridor)

    # Exclude certain percentage of results e.g.
    # 0.1 = is 10% percentile
    if (percentile < 1)
        max <- quantile(costCorridor_reclass,
            probs = c(percentile), na.rm = TRUE)

    # Exclude all values above a certain value
    # e.g. 0.08
    if (max < 1)
        costCorridor_reclass[costCorridor_reclass >
            max] = NA

    return(costCorridor_reclass)
}

## 20% percentile selects a relatively
## reasonable modern
costCorridorBetweenMandD_mod <- sw_costcorridor_scale(conductance_symm_
mod,
    point_sacred_gate, point_didyma_altar, percentile = 0.25)
# ancient
costCorridorBetweenMandD_anc <- sw_costcorridor_scale(conductance_symm_
anc,
    point_sacred_gate, point_didyma_altar, percentile = 0.25)

## output information about reclassified
## costCorridor costCorridorBetweenMandD_mod
```

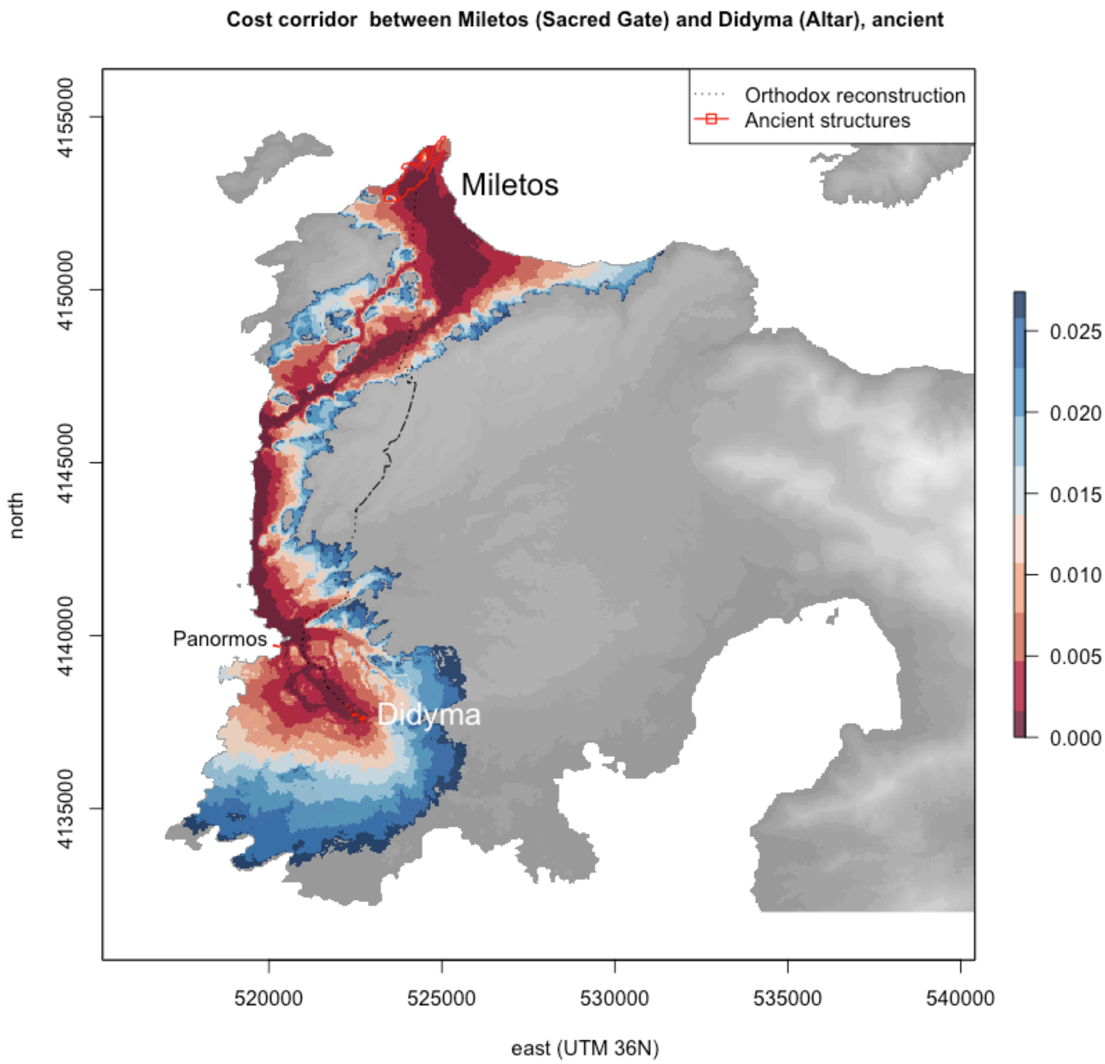
The resultant raster can be visualised geographically as follows:

```
sw_plot_costcorridor <- function(dem, costcorridor,
    map_suffix = "", lohmann = "", worldview = "") {
    # Create palette and plot map
    col.palette <- brewer.pal(10, "RdBu")
```

```
    # col.palette = heat.colors(30)
    ifelse((worldview == "yes"), alpha <- 0.5,
        alpha <- 0.8)
    sw_plot_map(dem, costcorridor, col = col.palette,
        alpha = alpha, title = paste("Cost corridor",
            map_suffix), lohmann = lohmann, worldview = worldview)
    if (worldview == "yes") {
        outline <- rasterToPolygons(costcorridor >
            0.6, dissolve = TRUE)
        plot(outline, col = NA, border = "white",
            lty = 1, lwd = 0.9, add = T)
    }
}

sw_plot_costcorridor(dem_modern, costCorridorBetweenMandD_mod,
    " between Miletos (Sacred Gate) and Didyma (Altar), modern")
sw_plot_costcorridor(dem_ancient, costCorridorBetweenMandD_anc,
    " between Miletos (Sacred Gate) and Didyma (Altar), ancient")
```



Cost corridor between Miletos (Sacred Gate) and Didyma (Altar), modern
Orthodox reconstruction
Ancient structures
Miletos
Panormos
Didyma
north
4155000
4150000
4145000
4140000
4135000
520000
525000
530000
535000
540000
east (UTM 36N)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000



FOCUS REGION: THE HARBOR REGION OF PANORMOS

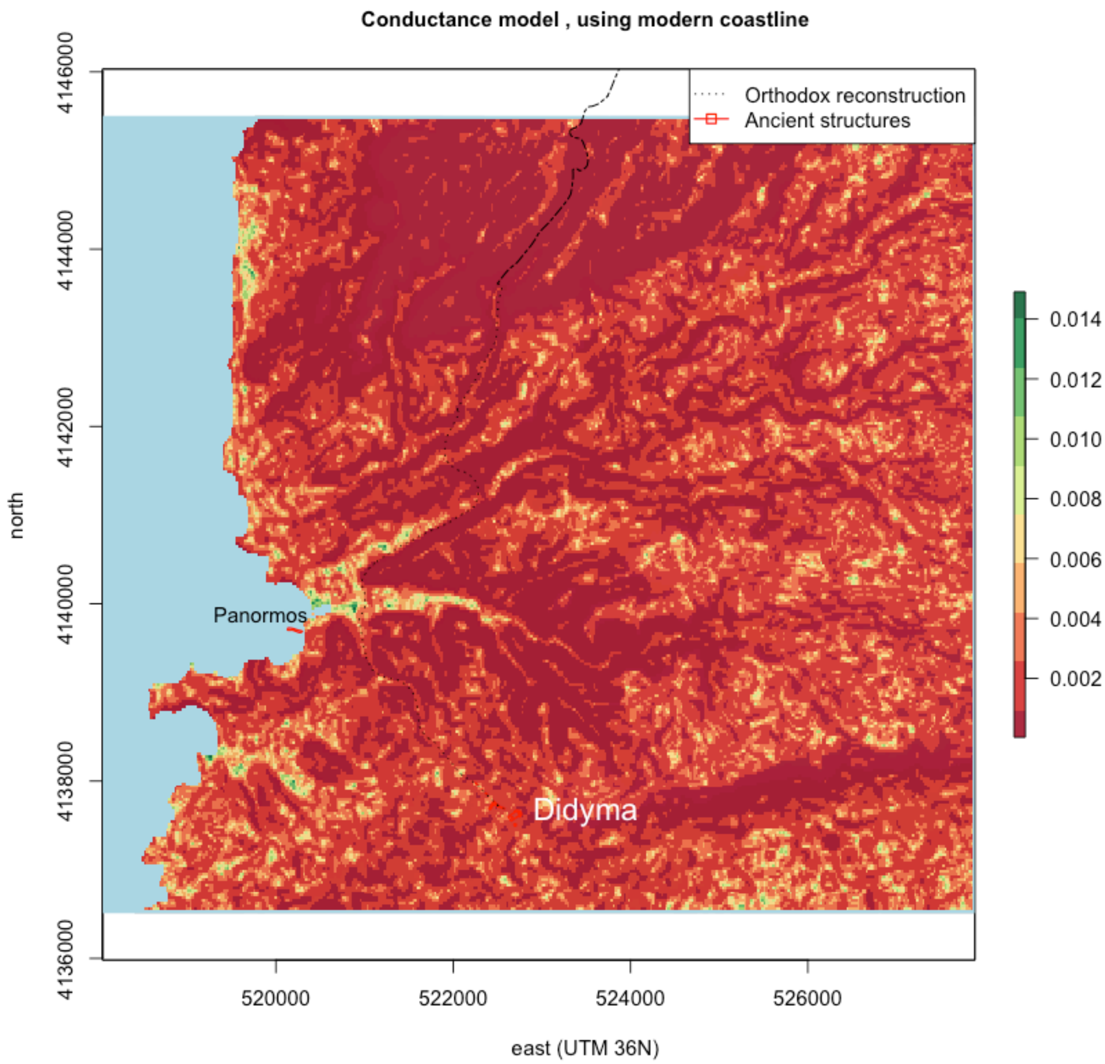
```
# plot maps side-by-side (nrows, ncols)
# uncomment this line if two charts should be
# plotted side-by-side par(mfrow=c(1,2))
```

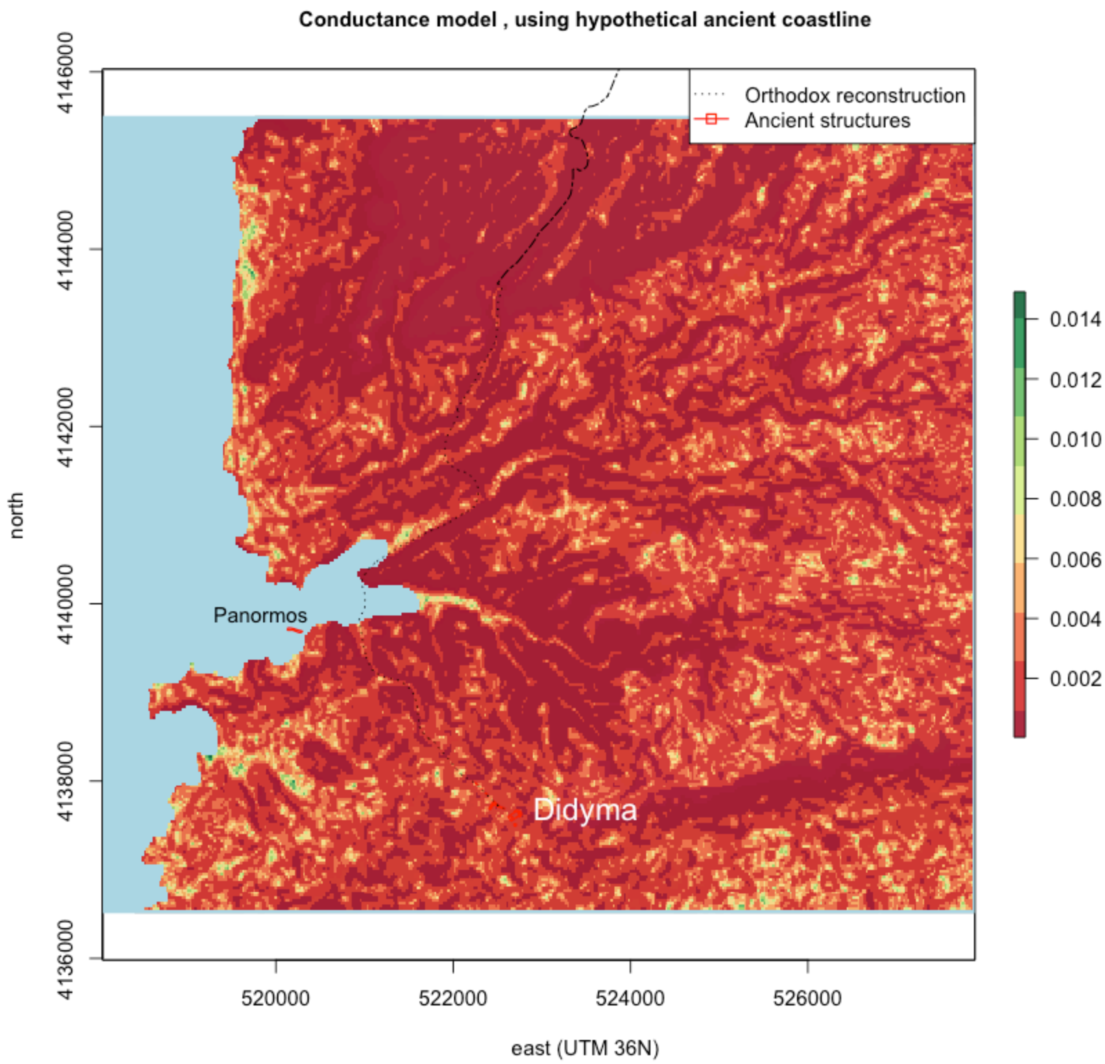
FOCUSING THE ANALYSIS AROUND THE UNCERTAIN SEGMENT NEAR PANORMOS

Using the basic models outlined above, we will focus the analysis on the region around the harbor of Panormos. Here, certain features of the landscape suggest the possibility that the coastline may have lain further inland than the current map suggests, which has consequences for the possible resistance/cost corridors and pathways which may have been favored.

Create a conductance model

```
# create sample symmetrical conductance using
# modern topography and plot as map
conductance_symm_mod <- sw_conductance(dem_wilski_modern,
    dirs = 16, symm = TRUE)
sw_plot_conductance(dem_wilski_modern, conductance_symm_mod,
    ", using modern coastline")

# create sample symmetrical conductance using
# ancient topography and plot as map
conductance_symm_anc <- sw_conductance(dem_wilski_prealluv,
    dirs = 16, symm = TRUE)
sw_plot_conductance(dem_wilski_prealluv, conductance_symm_anc,
    ", using hypothetical ancient coastline")
```


Conductance model , using modern coastline
Orthodox reconstruction
Ancient structures
Panormos
Didyma
north
east (UTM 36N)
4136000
4138000
4140000
4142000
4144000
4146000
520000
522000
524000
526000
0.002
0.004
0.006
0.008
0.010
0.012
0.014

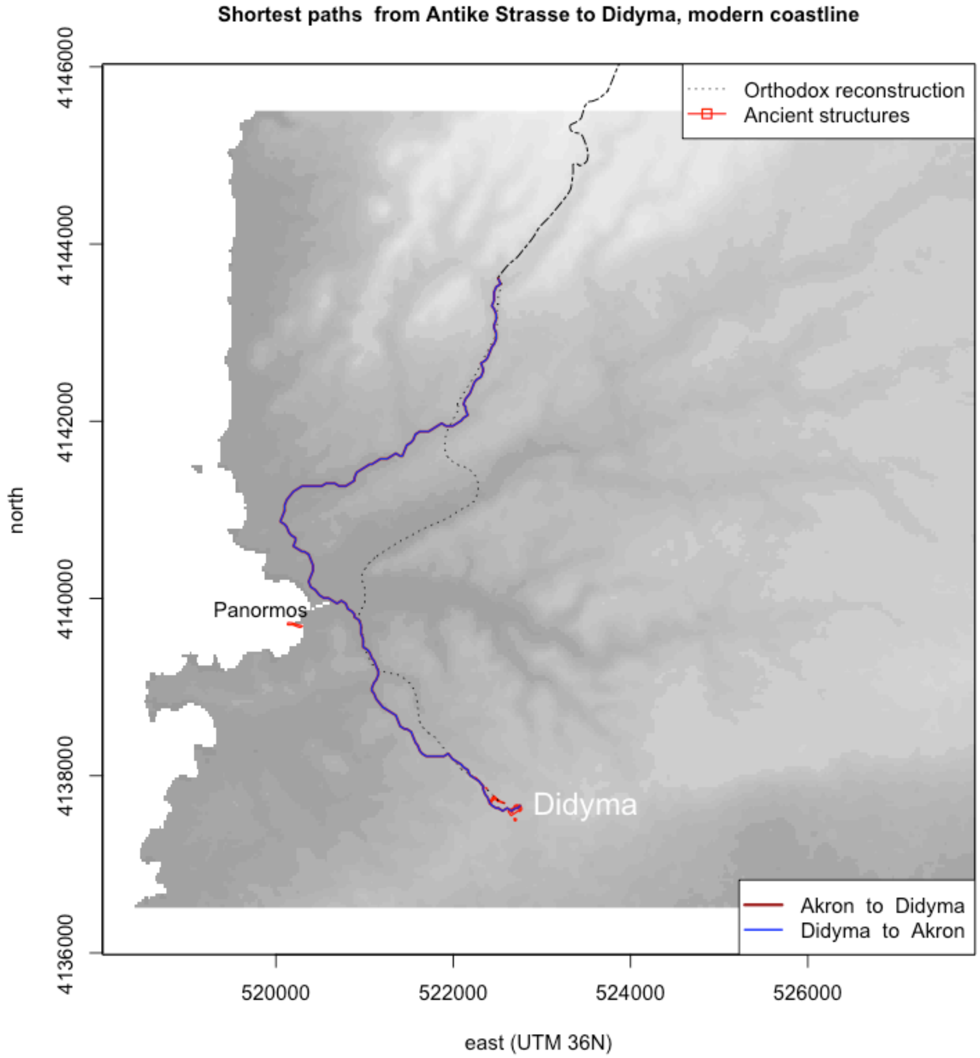


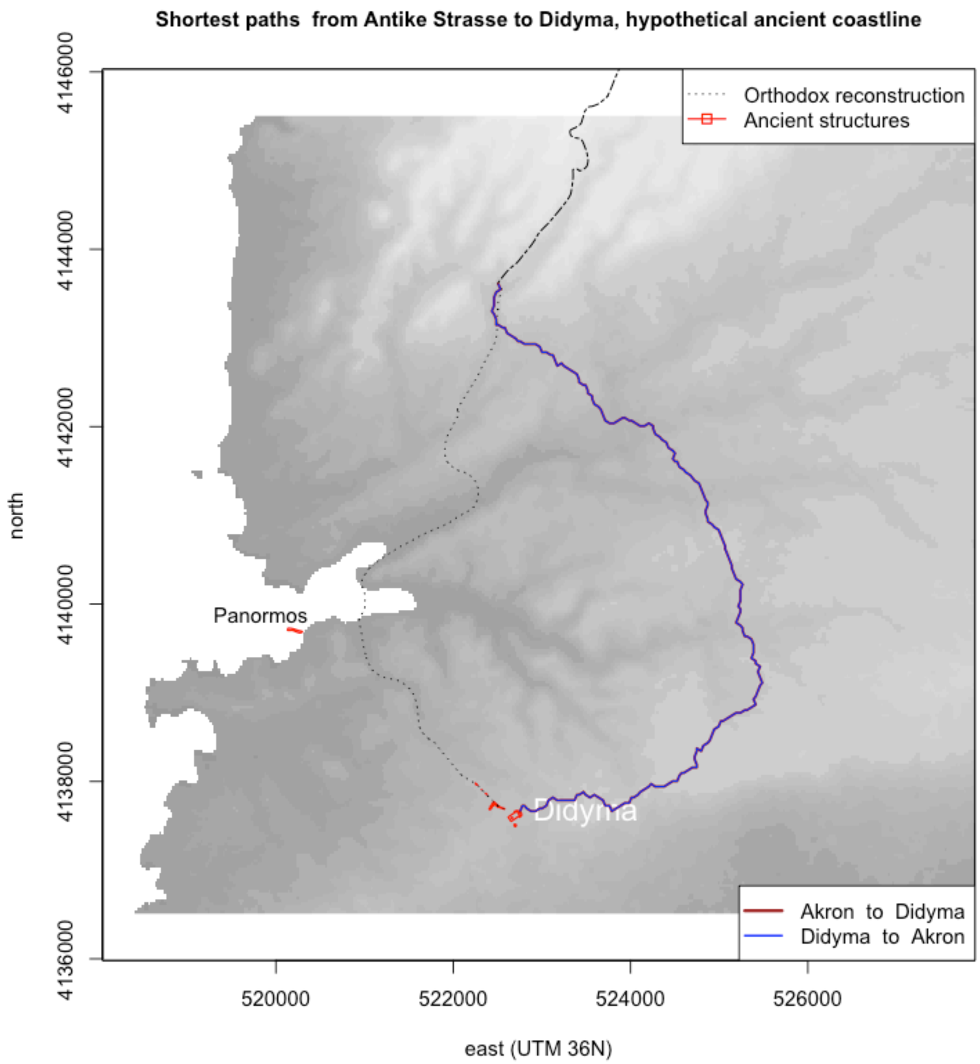
Create shortest path lines

We will assume here that Wilksi's Antike Strasse remains part of the Sacred Way for most of its history and therefore start our cost calculations from the point at which it leaves the Akron hills and becomes difficult to trace archaeologically (`point_road_leaving_akron`).

```
## using modern topography create assymetrical
## conductance transition
conductance_mod <- sw_conductance(dem_wilski_modern,
    dirs = 16, symm = FALSE)
# shortest path and its inverse
shortestpathAtoD_mod <- shortestPath(conductance_mod,
    point_road_leaving_akron, point_didyma_altar,
    output = "SpatialLines")
shortestpathDtoA_mod <- shortestPath(conductance_mod,
    point_didyma_altar, point_road_leaving_akron,
```

```
    output = "SpatialLines")

## using ancient topography create assymetrical
## conductance transition
conductance_anc <- sw_conductance(dem_wilski_prealluv,
    dirs = 16, symm = FALSE)
# shortest path and its inverse
shortestpathAtoD_anc <- shortestPath(conductance_anc,
    point_road_leaving_akron, point_didyma_altar,
    output = "SpatialLines")
shortestpathDtoA_anc <- shortestPath(conductance_anc,
    point_didyma_altar, point_road_leaving_akron,
    output = "SpatialLines")

# write line to file
sw_export_as_gml <- function(sl, filepath, layername) {
    df <- data.frame(len = sapply(1:length(sl),
        function(i) gLength(sl[i, ])))
    rownames(df) <- sapply(1:length(sl), function(i) sl@lines[[i]]@ID)
    writeOGR(SpatialLinesDataFrame(sl, data = df),
        paste(export_dir, filepath, sep = "/"),
        layername, driver = "GML", overwrite_layer = T)
}
sw_export_as_gml(shortestpathAtoD_anc, "shortestpathAtoD_hypothetical.g
ml",
    "shortestpathAtoD_hypothetical")
sw_export_as_gml(shortestpathAtoD_mod, "shortestpathAtoD_modern.gml",
    "shortestpathAtoD_modern")



# Plot the maps
sw_plot_shortestpathpair(dem_wilski_modern, shortestpathAtoD_mod,
    shortestpathDtoA_mod, " from Antike Strasse to Didyma, modern coast
line",
    "Akron", "Didyma")
sw_plot_shortestpathpair(dem_wilski_prealluv,
    shortestpathAtoD_anc, shortestpathDtoA_anc,
    " from Antike Strasse to Didyma, hypothetical ancient coastline",
    "Akron", "Didyma")
```


Shortest paths from Antike Strasse to Didyma, modern coastline
Orthodox reconstruction
Ancient structures
Panormos
Didyma
Akron to Didyma
Didyma to Akron
north
4136000
4138000
4140000
4142000
4144000
4146000
520000
522000
524000
526000
east (UTM 36N)



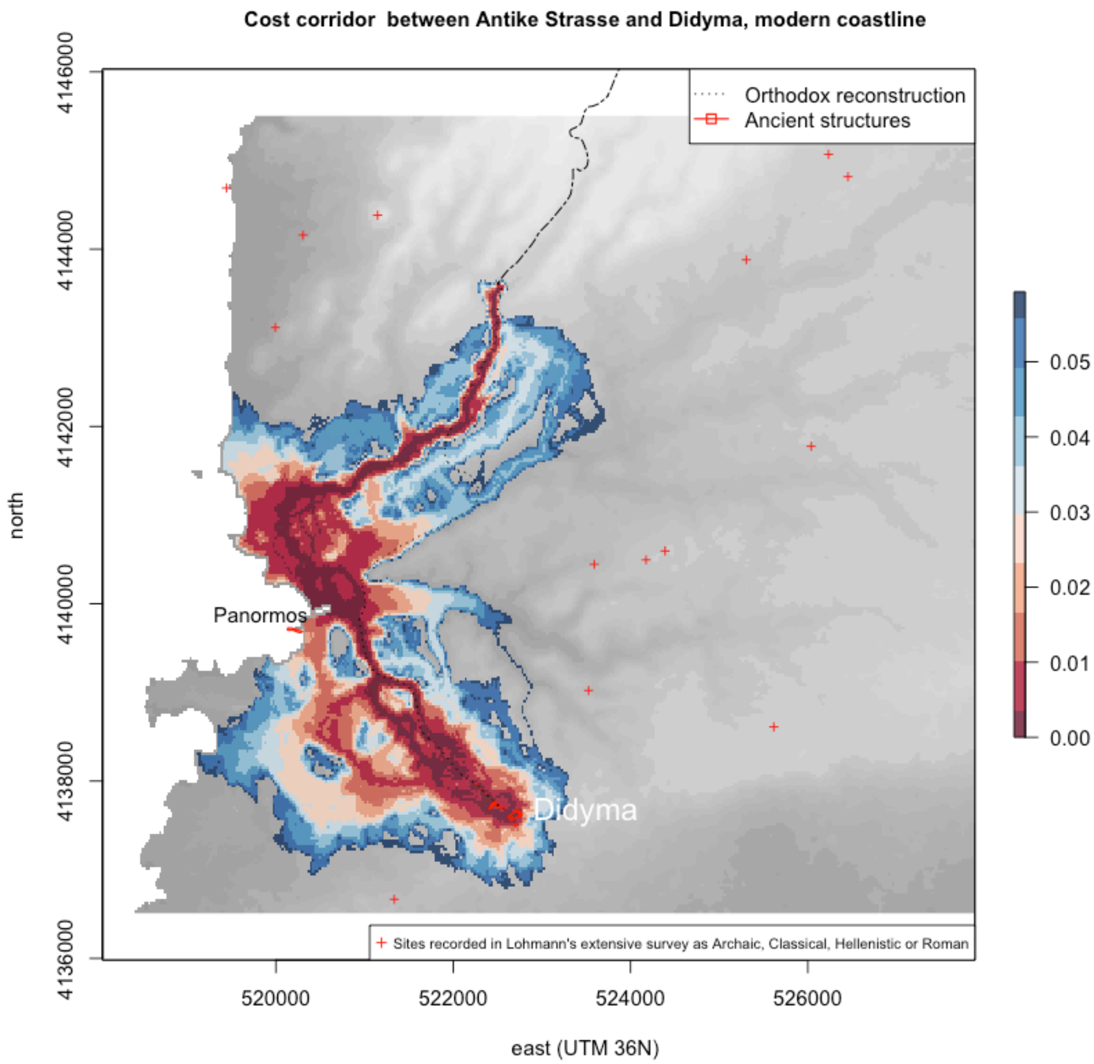
It is clear here, using the `simple_slope_conductance` model, that the effect of a relatively small change in the shape of the harbor can have a big effect on the shortest path: before alluviation, the shortest path lies far inland, refilling the harbor to roughly the modern (1960s) line, makes the shortest path follow a route quite close to the orthodox reconstruction.

Create cost-corridors

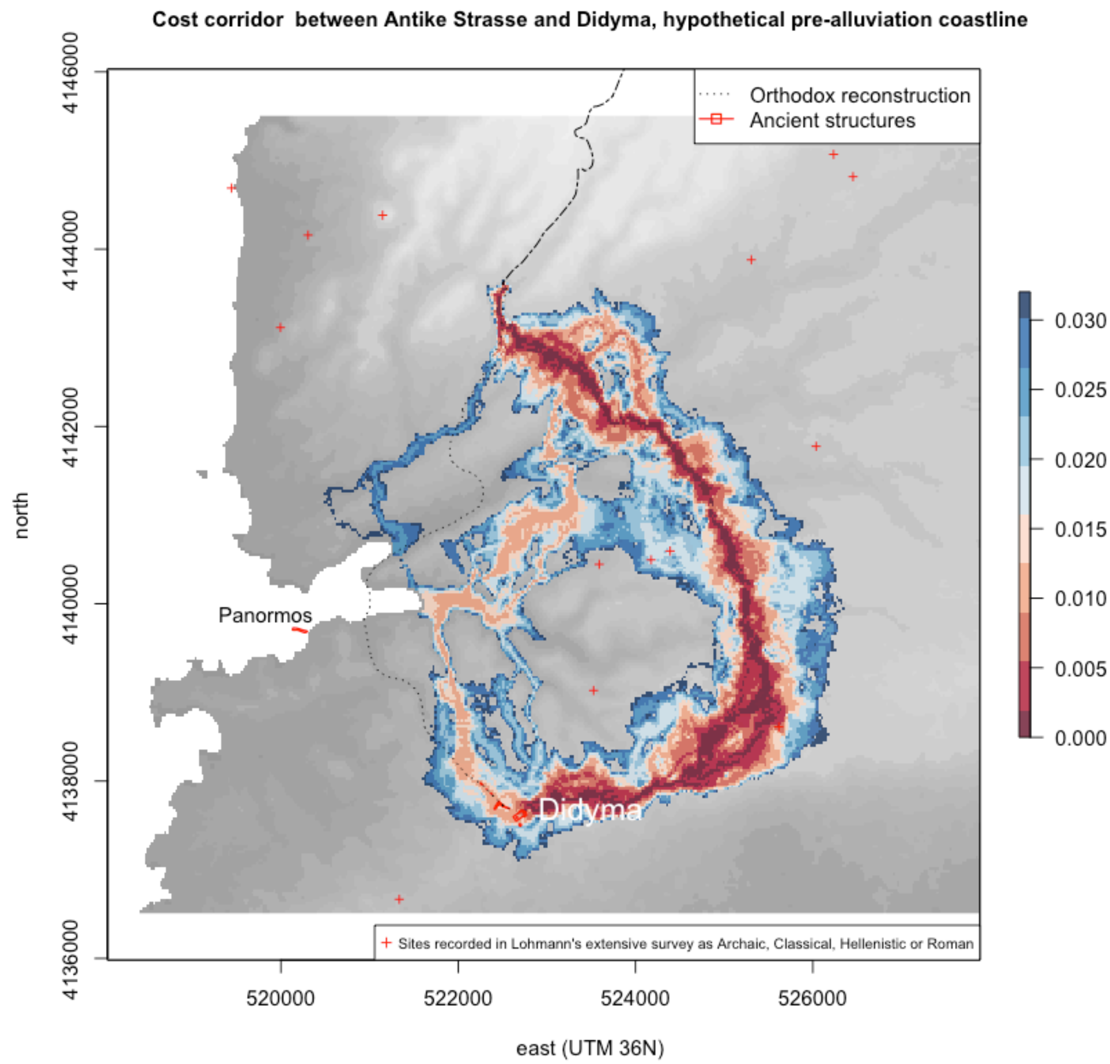
Again the shortest path line is in some senses more arbitrary since such a model cannot hope to predict an actual path accurately. The cost-corridor, however, offers a more nuanced probability layer.

```
# modern
costCorridorBetweenAandD_mod <- sw_costcorridor_scale(conductance_symm_
mod,
    point_road_leaving_akron, point_didyma_altar,
    percentile = 0.2)
```

```r
# ancient
costCorridorBetweenAandD_anc <- sw_costcorridor_scale(conductance_symm_
anc,
    point_road_leaving_akron, point_didyma_altar,
    percentile = 0.2)

# output information about reclassified
# costCorridor
costCorridorBetweenAandD_mod

## class       : RasterLayer
## dimensions  : 292, 400, 116800  (nrow, ncol, ncell)
## resolution  : 24.6, 30.8  (x, y)
## extent      : 518044, 527884, 4136509, 4145503  (xmin, xmax, ymin, y
max)
## coord. ref. : +proj=utm +zone=35 +datum=WGS84 +units=m +no_defs +ell
ps=WGS84 +towgs84=0,0,0
## data source : in memory
## names       : layer
## values      : 0, 0.05932335  (min, max)

# plot as maps
sw_plot_costcorridor(dem_wilski_modern, costCorridorBetweenAandD_mod,
    " between Antike Strasse and Didyma, modern coastline",
    lohmann = "yes")
sw_plot_costcorridor(dem_wilski_prealluv, costCorridorBetweenAandD_anc,
    " between Antike Strasse and Didyma, hypothetical pre-alluviation c
oastline",
    lohmann = "yes")

# export as raster
sw_export_geotiff <- function(rs, filepath) {
    writeRaster(rs, filename = paste(export_dir,
        filepath, sep = "/"), overwrite = T)
}
sw_export_geotiff(costCorridorBetweenAandD_anc,
    "costCorridorAtoD_hypothetical.tif")
sw_export_geotiff(costCorridorBetweenAandD_mod,
    "costCorridorAtoD_modern.tif")
```



Cost corridor between Antike Strasse and Didyma, modern coastline
Orthodox reconstruction
Ancient structures
Panormos
Didyma
Sites recorded in Lohmann's extensive survey as Archaic, Classical, Hellenistic or Roman
north
4136000
4138000
4140000
4142000
4144000
4146000
520000
522000
524000
526000
east (UTM 36N)
0.00
0.01
0.02
0.03
0.04
0.05



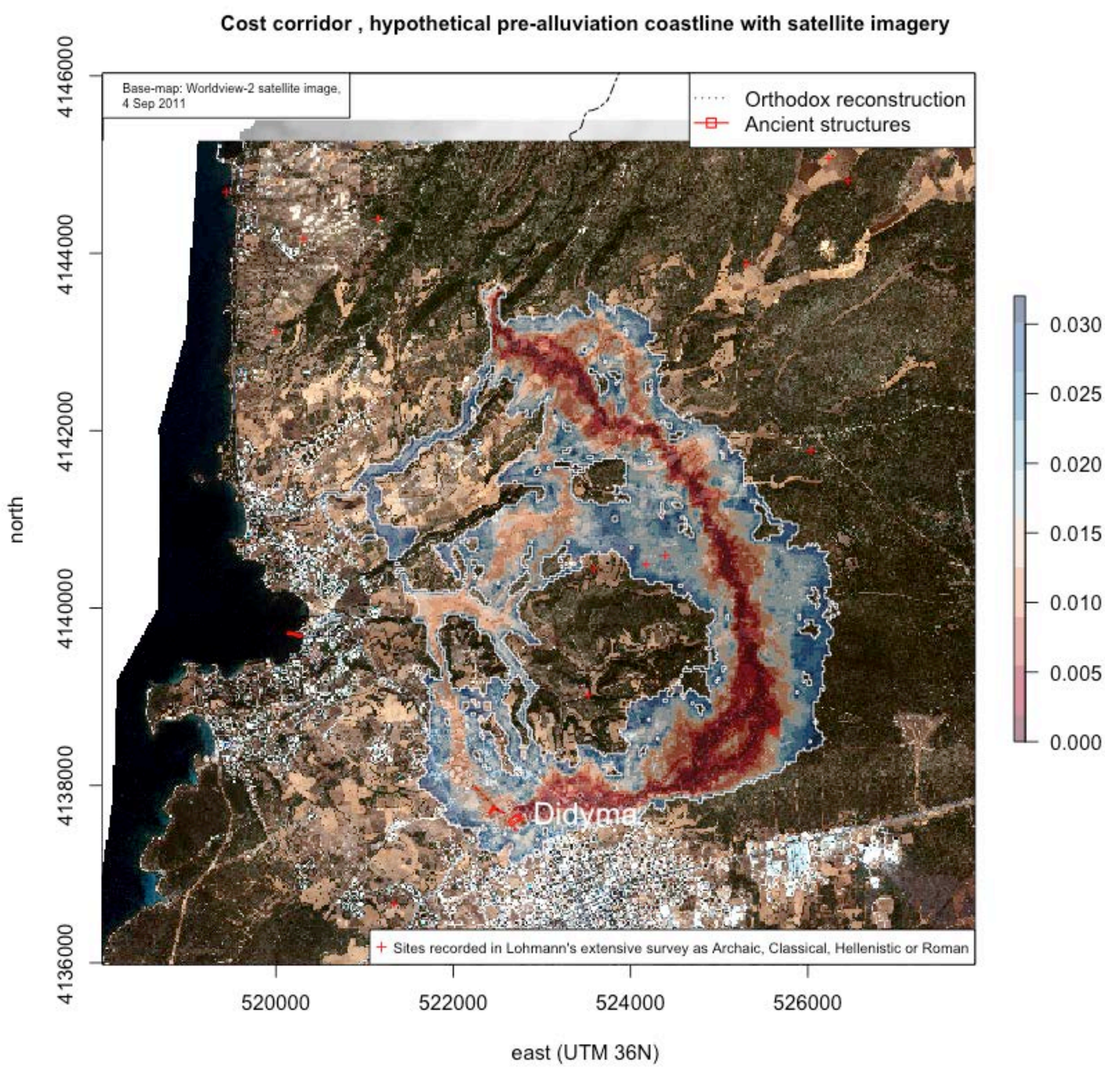
The post-alluviation (modern) cost-corridor from Akron to Didim runs to the coast, with the highest probability zone containing the orthodox reconstruction. An alternative corridor to the orthodox route is offered in the first section (when the cost-corridor skips a turn and heads straight to the coast) and around halfway (where it would be possible to travel around to the west of a set of low hills behind modern Mavişehir instead of along the modern main road).

The pre-alluviation cost-distance shows that the highest probability of movement runs far inland of the post-alluviation situation, albeit with two much lower probability corridors running somewhere halfway between the post-alluvial corridor and pre-alluvial maximum. In either case, the result is very similar to less nuanced shortest-path analysis: a difference in the topography around the harbor can make a substantial change to the probability of a route based incidentally or intentionally on slope-cost travelling through the Panormos harbor area or much further inland.

The pre-alluviation corridor (i.e., hypothetically ancient or original route) also approaches the sanctuary at Didyma area to the front of the Apollo temple.

As the location of sites from Lohmann's extensive survey show, this inland area, although relatively unused in the modern day (shown by the modern satellite imagery), actually has a number of sites dating to between ca. 800 B.C.E. and 400 C.E.

```r
# modern plot as maps
sw_plot_costcorridor(dem_wilski_prealluv, costCorridorBetweenAandD_anc,
    ", hypothetical pre-alluviation coastline with satellite imagery",
    lohmann = "yes", worldview = "yes")
```



Satellite imagery basemap, WorldView-2 ©

CONCLUDING COMMENTS

The variation in the shortest path and cost corridors created by potential changes in the shoreline support the possibility that, if travel cost was a factor in at least parts of the routing of the Sacred Way, routes other than the orthodox reconstruction could have been favored at different periods, as the affordances of the landscape changed through time.

Although these are merely heuristic models, they lend weight to the suggestion, based on epigraphical evidence, that a change of route could have been made following the infilling of the harbor, perhaps during the Late Hellenistic or Roman era. Geomorphological data may be able to provide better empirical evidence for the exact dating of any such alluviation process.

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BIBLIOGRAPHY

Bell, T., A. Wilson, and A. Wickham. 2002. "Tracking the Samnites: Landscape and Communications Routes in the Sangro Valley, Italy." *AJA* 106(2):169–86.

Dijkstra, E. 1959. "A Note on Two Problems in Connexion with Graphs." *Numerische Mathematik* 1(1):269–71.

Grewe, K., 2004. "Alle Wege führen nach Rom – Römerstraßen im Rheinland und anderswo." In "*Alle Wege führen nach Rom,*" *Internationales Römerstraßenkolloquium Bonn*, edited by H. Koschik, 9–42. Materialien zur Bodendenkmalpflege im Rheinland 16. Pulheim, Germany: Rhein Eifel Mosel-Verlag.

Herzog, I. 2013a. "The Potential and Limits of Optimal Path Analysis." In *Computational Approaches to Archaeological Spaces*, edited by A. Bevan and M. Lake, 179–212. London: Left Coast Press.

———. 2013b. "Theory and Practice of Cost Functions." In *Fusion of Cultures: Proceedings of the 38th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Granada, Spain, April 2010*, edited by F. Contreras, M. Farjas, and F.J. Melero, 375–82. *BAR-IS* 2494. Oxford: Archaeopress.

———. 2013c. “Review of Least Cost Analysis of Social Landscapes: Archaeological Case Studies [Book].” *Internet Archaeology* 34. http://dx.doi.org/10.11141/ia.34.7 .

Llobera, M., and T.J. Sluckin. 2007. “Zigzagging: Theoretical Insights on Climbing Strategies.” *Journal of Theoretical Biology* 249:206–17.

Marotte, R. 2015, 23 July. “Circuitscape VS. commuteDistance VS. costDistance.” Robby R. Marrotte (blog). http://robbymarrotte.weebly.com/blog/category/resistance-distance.

Minetti, A.E., C. Moia, G.S. Roi, D. Susta, and G. Ferretti. 2002. "Energy Cost of Walking and Running at Extreme Uphill and Downhill Slopes." *Journal of Applied Physiology* 93:1039–46.

Müllenhoff, M. 2005. *Geoarchäologische, sedimentologische und morphodynamische Untersuchungen im Mündungsgebiet des Büyük Menderes (Mäander), Westtürkei*. Marburg: Marbuger Geographische Gesellschaft.

Schneider, P. 1987. “Zur Topographie der Heiligen Straße von Milet nach Didyma.“ *AA*:101–29

van Etten, J. 2014. *R Package gdistance: Distances and Routes on Geographical Grids.* https://cran.r-project.org/web/packages/gdistance/vignettes/gdistance1.pdf .

van Etten J., and R. Hijmans. 2010. “A Geospatial Modelling Approach Integrating Archaeobotany and Genetics to Trace the Origin and Dispersal of Domesticated Plants. ” *PLOS ONE* 5(8):e12060.

Code repository

A raw version of this RMarkdown document, with any updates, will be made available from http://www.projectpanormos.com/sacredway/.