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On the Function of "Least-Cost Path" Calculations within the Project Tabula Imperii Byzantini (TIB) of the Austrian Academy of Sciences: a Case Study on the Route Melnik-Zlatolist (Bulgaria)[1]

I. Preconditions

I.1 Introduction

Melnik, the smallest town in the Republic of Bulgaria, is part of the district of Blagoevgrad. It lies 60 km south-south-east of the district's capital bearing the same name and 9,5 km south-east of the town of Sandanski.[2] Situated on the western slopes of the Pirin-mountains and at the river Melniška, an eastern confluent of the river Struma (Strymōn), Melnik is surrounded by sandstone cliffs, which were exposed to mechanical forces for centuries, thus shaping and altering the landscape constantly until the present day.[3]

The reconstruction of urban Melnik in the Late Byzantine period as well as the localisation of monuments within the town itself is possible on the basis of the written Greek and Slavonic sources – especially charters from the 13th and 14th centuries, which enable us to discern an "Upper town" and a "Lower town".[4] The same sources allow us to comprehend the structure of settlements

[1] This article derives from results achieved within the FWF – Austrian Science Fund project entitled 'Economy and Regional Trade Routes in Northern Macedonia (12th–16th Century)' (project P 21137-G19) under the supervision of o. Univ.-Prof. emer. Dr. Dr. h.c. Johannes Koder (Vienna). The necessary data has been gathered during two surveys in Bulgaria (12 June to 26 June 2007, 14 June to 27 June 2010) with the help of Mag. Dr. Peter Soustal (Vienna). To both of them and to the FWF – Austrian Science Fund I am grateful for their help and support. The first part of the article on the historical setting and the theoretical approach has been written by the project's scientific co-worker Mag. Dr. Mihailo St. Popović (Vienna), the second part comprising the mathematical explanation and the modelling by Ing. Dr. Juilson J. Jubanski (Munich) and the third part (*III. Summary*) by both authors together. All data has been processed with free- and shareware available on the Internet in order to show that such a case study can be conducted successfully at moderate cost.

[2] Cf. fig. 1.

[3] In fact this had a major impact on the case study to follow and had to be taken into consideration for the modelling of the "least-cost path". Cf. on the landscape surrounding the town of Melnik fig. 2.

[4] Cf. on this issue in detail with further hints to the secondary literature: Alexander Kazhdan, Melnik, in: The Oxford Dictionary of Byzantium 2. New York, Oxford 1991, 1337; Violeta Neševa, Melnik. Bogozidanijat grad. Sofija 2008, 49–70; Mihailo Popović, Did Dragōtas conquer Melnik in 1255?, *Glasnik Institut za Nacionalna Istorija* 51/1 (Skopje 2007), 15–24; Idem, Zur Topographie des spätbyzantinischen Melnik, *Jahrbuch der Österreichischen Byzantinistik* 58 (2008), 107–119; Idem, Neue Überlegungen zu der alten Metropolitankirche Sveti Nikola in Melnik als Ergänzung zur Forschung des Vladimir Petković, in: Mihailo Popović – Johannes Preiser-Kapeller (Eds.), Junge Römer – Neue Griechen. Eine byzantinische Melange aus Wien. Beiträge von Absolventinnen und Absolventen des

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in the region of Melnik in the Late Byzantine and Ottoman periods by applying the method of "Central Place Theory".[5]

What can be found neither in the above-mentioned mediaeval sources nor in the Ottoman taxation registers (*defter*) of the 16th century[6], is evidence on roads and routes[7] in Melnik's surrounding area. The question, which arises at this point, is, if the existing gap concerning the mediaeval road system in the area studied can be bridged by archaeological findings.

I.2 Archaeological evidence

Two routes emerge according to the archaeological secondary literature, which led from the valley of the river Struma (Strymōn) via the Pirin-mountains to the valley of the river Mesta (Nestos). The first connected Drangovo, Katunci and Gorno Spančevo, while the second linked Marikostinovo, Katunci and Gorno Spančevo. Another route via Damjanica and Melnik joined the two above-mentioned at Gorno Spančevo.[8] All three continued through the Pirin-massif to the town of *Nikopolis ad Nestum*.[9]

What is remarkable in this context, is the fact that no traces of roads were documented by Michael Wendel for the Early Byzantine period.[10] Nor does Paul Meinrad Strässle mention any remnants of roads from the Middle Byzantine period.[11] In addition, it seems that no surveys were conducted recently in the surrounding area of Melnik with the aim to reconstruct the network of routes on a micro-level – or at least no reports were written / published in this respect, with one exception from the 19th century, which will be discussed below (cf. *I.3*).

By recognising the lack of information in the mediaeval written sources and of archaeological evidence, it has to be concluded that a coherent picture

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5 Cf. on this topic: Mihailo St. Popović, Die Siedlungsstruktur der Region Melnik in spätbyzantinischer und osmanischer Zeit, *Zbornik Radova Vizantološkog Instituta* 47 (2010), 247–276.

6 In translation published by: Aleksandar Stojanovski (Ed.), Turski dokumenti za istorijata na Makedonskiot narod. Opširen popisen defter za Kjustendilskiot sandžak od 1570 godina. Tom V/Kniga 4. Skopje 1985, 13–148.

7 Cf. on the terms assigned to roads and routes in the Late Byzantine period on the basis of mediaeval charters: Klaus Belke, Roads and Travel in Macedonia and Thrace in the Middle and Late Byzantine Period, in: Ruth Macrides (Ed.), Travel in the Byzantine World. Aldershot 2002, 73–90; Mihailo St. Popović, Altstraßenforschung am Beispiel des Tales der Strumica bzw. Strumešnica in spätbyzantinischer Zeit (1259–1375/76), in: Miša Rakocija (Ed.), Niš i Vizantija. Osmi naučni skup, Niš, 3–5. jun 2009. Zbornik radova VIII. Niš 2010, 417–432.

8 Cf. fig. 3.

9 This outline is given by: Michael Wendel, Karasura III. Untersuchungen zur Geschichte und Kultur des alten Thrakien, Die Verkehrsanbindung in frühbyzantinischer Zeit (4.–8. Jh. n. Chr.). Langenweißbach 2005 (Schriften des Zentrums für Archäologie und Kulturgeschichte des Schwarzmeerraumes, 6), 141f., 159. The remnants of *Nikopolis ad Nestum* lie approximately 7 km north-east of the city Goce Delčev (the former Nevrokop). Cf. Peter Soustal, Thrakien (Thrakē, Rodopē und Haimimontos). Wien 1991 (reprinted Wien 2004) (Tabula Imperii Byzantini, 6), 376f.

10 Wendel, Karasura III, 282, 289, 298, 309, 323–325.

11 Paul Meinrad Strässle, Krieg und Kriegführung in Byzanz. Die Kriege Kaiser Basileios' II. gegen die Bulgaren (976–1019). Köln, Weimar, Wien 2006, 187–189.

of the routes around the town of Melnik for the Late Byzantine and Ottoman periods did not exist to this date.

I.3 Surveys

A first survey of the routes in the area of Melnik was conducted on 14 June 2007 by Peter Soustal and me (both *TIB*) within the FWF – Austrian Science Fund project 'Makedonien, nördlicher Teil / Macedonia, Northern Part' (*TIB* 16) (project P 18866-G02).[12] It was based on information provided by two inhabitants of Melnik, Asen and Vanja Miluševi.

According to them a route existed between the town of Melnik and the village of Zlatolist, leading via a pass called Goljam Ključ. On the pass itself a deserted observation post could be found. This route was still used every day during the 20th century by Zlatolist children to go to school in Melnik until its closure. Moreover, a sketch of the route was drawn by Vanja Miluševa.[13]

The starting point of the survey on 14 June 2007 was Kordopulov's house (Kordopulova kăšta)[14] at the south-eastern edge of Melnik. Turning to the south-east, my colleague Peter Soustal and I entered a forest and continued on a forest road, until we reached the church of Sveta Petka (Sveta Paraskeva) on an elevation.[15] This church is dated to the first half of the 13th century and supposedly was erected on structures from the 6th century AD.[16] It has three naves and its wooden roof truss is supported by wooden pillars.

At this point the route's ascending slope increased considerably and led through dense vegetation cover consisting of trees and scrub.[17] The character of the route on the northern versant towards Melnik changed from a mule track[18] to a broader path (up to circa 2,5 m) in the immediate vicinity

[12] Cf. on this project: http://www.oeaw.ac.at/byzanz/tib014.htm (accessed 27 July 2010); Mihailo St. Popović, The Project *Tabula Imperii Byzantini (TIB)* of the Austrian Academy of Sciences, *Ostkirchliche Studien* 58/2 (2009), 267–272, 271f.; Idem, Mapping Byzantium – The Project "Macedonia, Northern Part" in the Series Tabula Imperii Byzantini (TIB) of the Austrian Academy of Sciences, in: K. Kriz – W. Cartwright – L. Hurni (Eds.), Mapping Different Geographies. Berlin, Heidelberg 2010 (Lecture Notes in Geoinformation and Cartography), 219–234.

[13] Cf. fig. 4. My explanations to the sketch are amended in brackets. I thank Asen and Vanja Miluševi (Melnik) sincerely for their help.

[14] GPS (Global Positioning System) 23 23 53; 41 31 22. The GPS-waypoints were recorded with Garmin GPSmap 60CSx as well as Garmin Oregon 550t and are all listed in fig. 5 at the end of this chapter. Furthermore, the waypoints and the track between Melnik and Zlatolist are visualised with Google Earth in fig. 6.
Kordopulov's house was built in 1754 and is a museum today: Tchavdar Marinov, De la « ville grecque » au musée bulgare : l'invention d'un patrimoine national à Melnik, *Revue des Études Sud-Est Européennes* 47/1–4 (2009), 239–271, 262–267; Theodoros N. Vlachos, Die Geschichte der byzantinischen Stadt Melenikon. Thessaloniki 1969 (Hetaireia Makedonikōn Spudōn, Hidryma Meletōn Chersonēsu tu Haimu, 112), 57f. Cf. fig. 7. The slight difference between the starting point of the route documented on 16 June 2010 between Melnik and Zlatolist and the starting point of the "least-cost path" lies in the fact that the recording of the route began at the foot of Kordopulov's house, while the GPS-waypoint of the house itself was used for the model.

[15] GPS 23 24 05; 41 31 14. Cf. figs. 8, 9 and 10.

[16] Neševa, Melnik. Bogozidanijat grad, 69, 292; Violeta Neševa – Cvetana Komitova, Cărkvata „Sv. Paraskeva" (Sv. Petka) v Melnik, *Arheologija* 46/1–4 (2005), 100–108. Cf. fig. 11.

[17] Cf. fig. 12.

[18] Cf. fig. 13.

of the pass Goljam Ključ[19], which could be used by carriages if substantially cleared. No traces of paving could be discerned on the northern versant.

As described by Asen and Vanja Miluševi, remnants of a rectangular building were indeed to be found on the southern exit of the pass.[20] This building looks to the south, thus partly overlooking the route between Goljam Ključ and Zlatolist.[21] It was documented by Bulgarian archaeologists[22] and identified as a tower with a length of 6,55 m and a breadth of 4,18 m. Its height was estimated at 10 to 12 m, which means that it should have had at least three floors. The tower was dated to the 6th century AD[23], which in my opinion has to be questioned due to the lack of well-grounded evidence (i.e. relevant findings). The pass of Goljam Ključ and its tower formed a part of Melnik's mediaeval outer fortification system, being a strategic narrow point and at the same time the only connection of the town to the south-east and hence to the east.[24]

Moreover, it could well be that the toponym of Goljam Ključ appears in the will of Paulos Klaudiupolitēs, the archbishop of Melnik, in 1216, wherein he donated a vineyard in *Kleiutzitos* (*kai heteron ampelion eis ton Kleiutziton*) to the monastery Theotokos Spēlaiōtissa in the "Upper town" of Melnik.[25] This identification is fostered by the similarity between the Greek words *kleis* / *kleidion*[26] and the Slavonic word *ključь*[27], both meaning "key", which again refers to this pass as a narrow point.[28]

By descending the southern versant towards Zlatolist, we encountered traces of paving with an overall length of approximately 75 m, which show characteristics of a paved mule track.[29] Then the slope passed gently into a

19 Cf. fig. 14.

20 GPS 23 24 24; 41 31 06. Cf. figs. 9 and 15.

21 GPS 23 24 36; 41 30 50. This GPS-waypoint marks the line of sight between a traveller coming from the south (from Zlatolist) and the observation post at Goljam Ključ. Cf. figs. 16 and 17.

22 Boris Hristov Cvetkov, Selištnata mreža v dolinata na Sredna Struma prez Srednovekovieto IX–XVII vek (po arheologičeski danni). Sofija 2002, 57, 197–199; Cvetana Komitova, Arheologičesko proučvane na obekt "Krepostna kula" v m. Ključ kraj gr. Melnik, in: Arheologičeski otkritija i razkopki prez 2003 g. Sofija 2004, 199f.; Neševa, Melnik. Bogozidanijat grad, 62, 70f.; Georgi Stojanov, Naprečna krepostna stena iztočno ot căkva "Sv. Nikola" – etap ot krepostnoto stroitelstvo na Melnik XIII–XIV vek, *Prinosi kăm bălgarskata arheologija* 1 (1992), 158–163, 159.

23 Cf. for all the details and a plan: Violeta Neševa, Melnik pri car Samuil v kraja na X – načaloto na XI vek (po arheologičeski danni), in: Vizantija, Balkanite, Evropa. Izsledvanija v čest na Prof. Vasilka Tăpkova-Zaimova. Sofija 2006 (Studia Balcanica, 25), 605–622, 615f., 622; Eadem, Melnik. Bogozidanijat grad, 70.

24 Cvetkov, Selištnata mreža, 57; Stojanov, Naprečna krepostna stena, 159.

25 His will was edited in: Jacques Bompaire – Jacques Lefort – Vassiliki Kravari – Christophe Giros (Eds.), Actes de Vatopédi I. Des origines à 1329. Texte. Paris 2001 (Archives de l'Athos, 21), 122f. (No. 12). Also cf. Violeta Neševa, Melniškijat manastir „Sv. Bogorodica Spileotisa" („Sv. Zona") v novi dokumenti, in: Sbornik v pamet na profesor Velizar Velkov. Sofija 2009, 519–531; Popović, Zur Topographie, 113, 115. Cf. on the proposed identification: Neševa, Melnik. Bogozidanijat grad, 17.

26 Henry G. Liddell – Robert Scott – Henry S. Jones, A Greek-English Lexicon. Oxford 1996, 956f.

27 Franz von Miklosich, Lexicon Palaeoslovenico-Graeco-Latinum emendatum auctum. Wien 1862–1865 (reprinted Aalen 1977), 292.

28 Goljam Ključ is not to be mistaken for Malăk Ključ. Malăk Ključ lies approximately 800 m east-south-east to Goljam Ključ (cf. map 1:55,000, Turističeska karta, Pirin, Sofija [10]2006) and was also charted by Vanja Miluševa in fig. 4. Also cf. fig. 3.

29 The starting and the finishing point of the paving were recorded with two GPS-waypoints [GPS 23 24 29; 41 31 01 and GPS 23 24 29; 41 30 58]. Cf. figs. 16, 18 and 19.

valley, which is grassy, thus similar to a mountain pasture,[30] and led on a farm track to the south, until it reached first the church of Sveti Georgi[31] and then the village of Zlatolist[32].

Shortly after this first survey a project entitled "Melnik – God Created Town From Demolition to a Raise" started in July 2007. It was financed by the European Union within the Phare CBC Programme between Bulgaria and Greece for the "Promotion of nature protection actions and sustainable development across the border".[33] One of its aims was the development of eco-paths in the triangle between the village of Zlatolist, the monastery of Rožen[34] and the town of Melnik in the period 18 July 2007 until 15 November 2007. Visible measures, which were taken by the above-mentioned project on this occasion and which we documented during our second survey on 16 June 2010, were the construction of resting places, benches and wooden handrails along steep sections of the path.

In the meantime, research within the FWF – Austrian Science Fund project 'Economy and Regional Trade Routes in Northern Macedonia (12th–16th Century)' (project P 21137-G19)[35] has revealed that our survey of the route between Melnik and Zlatolist conducted in 2007 was not the first scientific study at all.

The Viennese archives preserve invaluable records of reconnaissance undertaken by the *k. k. Militär-Geographisches Institut* in South-East Europe during the 19th century.[36] Since the 1870s Austro-Hungarian officers had set out for expeditions through the Balkan peninsula in order to map routes

[30] Cf. fig. 20.

[31] GPS 23 24 56; 41 29 55. According to an inscription on the outer eastern wall above the apse the church was erected in 1857. The frescoes date to the year 1876. Cf. figs. 21 and 22.

[32] GPS 23 25 11; 41 29 43. The former name of this village was Dolna Sušica. It was renamed as Zlatolist in the year 1951. Cf. Petăr Koledarov – Nikolaj Mičev (Eds.), Promenite v imenata i statuta na selištata v Bălgarija 1878–1972 g. Sofija 1973, 115. Cf. also figs. 21 and 23.

[33] The project's number is BG 2004/016–782.01.03.03.09–08. For further information in the Internet: http://ec.europa.eu/enlargement/fiche_projet/document/2004-016-782.01.03%20Nature.protection.pdf (accessed 28 July 2010); www.mrrb.government.bg/download.php?id=dmlhbGl8MTM4 (accessed 28 July 2010).

[34] Cf. on the history of this monastery: Georgi Gerov et al., Stenopisite na Roženskija manastir. Sofija 1993; Zoe Kazazaki et al., Monasteries of the Via Egnatia. Cultural – Tourist guide. 2. Central and Eastern Macedonia, Thrace – Southern FYROM – Southern Bulgaria. Heraklion 1999, 128–132; Sōtērios Kissas, Contribution to the History of Rožen Monastery near Melnik, *Cyrillomethodianum* 11 (1987; published 1989), 195–213; Ljuben Praškov – Elka Bakalova – Stefan Bojadžiev, Manastirite v Bălgarija. Sofija 1992, 244–252.

[35] Cf. on this project: http://www.oeaw.ac.at/byzanz/routes.htm (accessed 28 July 2010).

[36] On the history of the *k. k. Militär-Geographisches Institut*: Franz Almer, Das k.u.k. militärgeographische Institut, *Communications in Asteroseismology* 149 (2008), 75–82; Robert Messner, Das Wiener Militärgeographische Institut. Ein Beitrag zur Geschichte seiner Entstehung aus dem Mailänder Militärgeographischen Institut, *Jahrbuch des Vereines für Geschichte der Stadt Wien* 23/25 (1967/1969), 206–292; Idem, Das kaiserlich-königliche Militärgeographische Institut zu Mailand. L'imperiale regio Istituto Geografico Militare a Milano. 1814–1839. 25 Jahre österreichische Militärgeographie in Italien. Wien 1986; Michael Ponstingl, „Der Soldat benötigt sowohl Pläne als auch Karten." Fotografische Einsätze im k. (u.) k. Militärgeographischen Institut zu Wien. Teil I/Teil II, *Fotogeschichte. Beiträge zur Geschichte und Ästhetik der Fotografie* 81 (2001), 39–56 and 83 (2002), 53–82. I am grateful to Thomas Knoll (BEV – Bundesamt für Eich- und Vermessungswesen/Vienna) for his kind advice and support. On the *Bundesamt für Eich- und Vermessungswesen*, the successing organisation of the *k. k. Militär-Geographisches Institut*: http://www.bev.gv.at/portal/page?_pageid=713,1604790&_dad=portal&_schema=PORTAL (accessed 28 July 2010).

between settlements and to sketch hachures of the terrain in preparation of the famous Austrian maps on the scale of 1 : 200,000.[37]

Vinzenz Karl Haardt von Hartenthurn (1843–1914), director of the first department of the *k. k. Militär-Geographisches Institut* from 1897 until 1914[38], describes the importance of these expeditions as follows: "Als feste und unveränderliche Linien bei dem Entwurfe der vorerwähnten Generalkartenblätter [scilicet on the scale of 1 : 200,000] galten vor allem die Skizzen, welche sich aus den 1871–1875 von Officieren des militär-geographischen Institutes durchgeführten astronomischen Ortsbestimmungen und topographischen Routen-Aufnahmen ergaben."[39]

The value of the above-mentioned records of reconnaissance from the 1870s lies without doubt in the fact that they document the preindustrial condition of routes in South-East Europe.[40] Their analysis has shown that Austro-Hungarian officers did not only visit Ottoman Rumelia in the year 1874[41], but that they also surveyed the same route between Melnik and Šušica (i.e. Zlatolist)[42] on 19 June 1874 as we did on 14 June 2007.

Their drawing[43] clearly shows that they travelled in one day from Melnik

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[37] Cf. the following reports: Vincenz [sic!] Haardt von Hartenthurn, Begleitworte zu den Blättern der Generalkarte 1 : 200.000, welche die Balkan-Halbinsel betreffen, *Mittheilungen des kaiserl. und königl. Militär-Geographischen Institutes* 17 (1897), 80–86; Vinzenz Haardt von Hartenthurn, Die Tätigkeit des k. u. k. Militärgeographischen Institutes in den letzten 25 Jahren (1881 bis Ende 1905.). Wien 1907, 291–312; Johann Levačić, Die Schreibung der geographischen Namen auf der Balkan-Halbinsel, *Mittheilungen des kaiserl. und königl. Militär-Geographischen Institutes* 17 (1897), 67–74; *Mittheilungen des kaiserl. königl. Militär-Geographischen Institutes* 7 (1887), 22–30; *Mittheilungen des kaiserl. und königl. Militär-Geographischen Institutes* 22 (1902), 476–489. Unfortunately, I did not find any records on the expedition's composition or on an agreement between the Austro-Hungarian and the Ottoman Empire concerning a cooperation in the field of map-making. Only the name of *A. Magdeburg* appears on some of the sketches of hachures. Cf. in detail footnote 41. Cf. on the technique of making maps in general: Werner Heriszt, Kartenkunde. Wien [5]2001 (Truppendienst-Taschenbuch, Band 9); Jove Dimitrija Talevski, Voena Topografija. Bitola 1999.

[38] On his biography: Österreichische Akademie der Wissenschaften (Ed.), Österreichisches biographisches Lexikon: 1815–1950, 2. Band. Wien 1959, 116f.; http://www.deutsche-biographie.de/pdfNDB_n07-370-02.pdf (Neue Deutsche Biographie Onlinefassung; accessed 29 July 2010).

[39] Haardt von Hartenthurn, Begleitworte, 82.

[40] Their overall state in the historical region of Macedonia is described in the following publication: Militär-Geographie. Macedonisches Becken mit dem albanesischen Küstengebiete. Mit 7 Tafeln und 6 Beilagen. Wien 1886.

[41] The whole collection of records is entitled: Recognoscierungs – Skizzen in der Türkei. Reise in Rumelien 1874. Von A. Magdeburg. 1:144.000. Schichten und Schraffen. Wien 1874, 41 Blatt. It comprises south-western Bulgaria, northern Greece and Thrace. Moreover, the name *A. Magdeburg* appears on some of the sketches of hachures within the collection. Cf. Österreichisches Staatsarchiv (Vienna, Austria), Kriegsarchiv, B III c 19–04. According to the *Kais. Königl. Militär-Schematismus*, Albert Freiherr von Magdeburg was lieutenant ("Oberlieutenant") of the engineer regiment ("Pionnier-Regiment") and was assigned to the *k. k. Militär-Geographisches Institut* in 1874. Cf. Kais. Königl. Militär-Schematismus für 1874. Wien 1874, 525. On the Magdeburg family in general: Constant von Wurzbach, Biographisches Lexikon des Kaiserthums Oesterreich. Sechzehnter Theil: Londonio – Marlow. Wien 1867 (reprinted Bad Feilnbach 2001), 260–262.

[42] Cf. on the name Šušica footnote 32.

[43] Cf. figs. 24a and 24b. This drawing is preserved in: Österreichisches Staatsarchiv (Vienna, Austria), Kriegsarchiv, B III c 19–04, Blatt XXX.

via Šušica (Zlatolist) and Čerešnica[44] to Ispanča[45] and finally reached Perim Köi[46]. Furthermore, they kept a diary of their journey, which reads as follows on the route between the town of Melnik and the village of Pirin[47]:

Marsch 32

VON MELNIK BIS PERIM KÖI 2½ MEILEN[48]

Beschaffenheit:	*Saumpfad mit kurzer Unterbrechung durch nicht erh.*[scilicet -altenen] *Fahrweg im Bistrica*[49] *Thale.*
Terrain:	*Erdiger, fester Boden bis Ispanča, dann steinig und felsig.* *Bis Ispanča Felder und Hutweide*[50] *– dann Wald und Gestrüpp.* *Steile Abfälle, schluchtartig eingerißene Wässer.* *Bistrica reißender Fluß – großes Gefälle, felsiges, schottriges Bett.*
Brücken:	*Kleine gewölbte Brücke über die Wässer.* *Bei Ispanča Bogenbrücke ohne Mittelpfeiler.*
Orte und Lagerplätze:	*Melnik –* *Šušica –* *Čerešnica –* *Ispanča –* *Perim Köi – 100* [scilicet Häuser[51]] *hier etwas Eisengewinnung*
Miltär.	
[scilicet -isch] *wichtig:*	–
Seitenwege:	–

These circumstances urged Peter Soustal and me to intensify our research on the routes in the surrounding area of Melnik on the basis of the above-mentioned FWF – Austrian Science Fund project. That is why additional surveys were conducted in the period between 16 June and 18 June 2010 in order to track all existing routes with GPS (Global Positioning System).[52]

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[44] They used a route between Šušica (Zlatolist) and Čerešnica, which is today called *Čerešniški păt* (cf. map 1:55,000, Turističeska karta, Pirin, Sofija [10]2006 and fig. 3). This is revealed by a thorough comparison between their drawing and the above-mentioned hiking map. Čerešnica lies approximately 6 km east-south-east from Melnik [GPS 23 27 31; 41 29 42].

[45] Ispanča is identical to Gorno Spančevo, which lies ca. 9 km east-south-east from Melnik [GPS 23 30 06; 41 30 08].

[46] Today the village of Pirin, approximately 14 km east-north-east from Melnik [GPS 23 33 37; 41 32 37]. The Turkish word "köy" means "village". Cf. fig. 25.

[47] Österreichisches Staatsarchiv (Vienna, Austria), Kriegsarchiv, B III c 19–04, Marsch 32.

[48] One Austrian mile [österreichische (Post-)Meile] = 7,585936 km. Therefore, 2,5 Austrian miles equal 18,96484 km. The metrical system was introduced in the Austro-Hungarian Empire on 23 July 1871 and was binding only since 1 January 1876. That is why the officers still used Austrian miles during their survey in 1874. Cf. Reichsgesetzblatt für die im Reichsrathe vertretenen Königreiche und Länder, VI. Stück, Ausgegeben und versendet am 2. März 1872: 16. Gesetz vom 23. Juli 1871, womit eine neue Maß- und Gewichtsordnung festgestellt wird, 29–34.

[49] The Bistrica mentioned in this diary is the Pirinska Bistrica, which is an eastern confluent of the river Struma (Strymōn) and has a length of 53 km. Cf. Enciklopedija Bălgarija 1, A–V. Sofija 1978, 290.

[50] In this context a "Hutweide" signifies agricultural land, which was used to graze domestic animals under surveillance of a shepherd or a juvenile. Cf. Hans BLESKEN et al. (Eds.), Deutsches Rechtswörterbuch. Wörterbuch der älteren deutschen Rechtsprache. Sechster Band (Hufenwirt bis Kanzelzehnt). Weimar 1961–1972, 134 ("Weideplatz"), 186.

[51] This interpretation is based on a comparison of this part of the diary with other parts.

[52] Cf. fig. 26.

The first route to be documented on 16 June 2010 was the known one between Melnik and Zlatolist via Goljam Ključ (in red).[53] The second track comprised the route between Melnik and the monastery of Rožen, which was recorded on 17 June 2010 (in blue).[54] The third and last route was the one between the monastery of Rožen and Zlatolist, which was tracked on 18 June 2010 (in turquoise).[55] All three routes form – together with the terrain's characteristics – the triangle Melnik-Rožen-Zlatolist.

***Fig. 5* List of GPS-waypoints**

Kordopulov's house	23 23 53; 41 31 22
Sveta Petka	23 24 05; 41 31 14
Tower at Goljam Ključ	23 24 24; 41 31 06
Starting point paving	23 24 29; 41 31 01
Finishing point paving	23 24 29; 41 30 58
Line of sight	23 24 36; 41 30 50
Sveti Georgi	23 24 56; 41 29 55
Zlatolist	23 25 11; 41 29 43
Čerešnica	23 27 31; 41 29 42
Gorno Spančevo	23 30 06; 41 30 08
Pirin	23 33 37; 41 32 37

I.4 Working hypothesis

At this point it is necessary to summarise the information presented so far. Although there is lack of evidence on the roads in the surrounding area of the town of Melnik in the mediaeval sources as well as in the archaeological documentation, it is nevertheless possible to ascertain the following facts concerning the route between Melnik and Zlatolist, on which we will henceforth focus our efforts:

a) one indication in a will from the year 1216 naming the toponym *Kleiutzitos*, which should most probably be identified with the narrow point of Goljam Ključ
b) isolated archaeological evidence in form of a tower at Goljam Ključ and traces of paving on the southern versant towards Zlatolist

[53] The technical data of the recorded track reads as follows: Average speed: 2,0 km/h; Maximum speed: 8,2 km/h; Total time: 02:07:47; Cartographic length = 4,184 km. The total time has to be rectified to approximately 90 minutes, because the remaining time of 37:47 minutes was used for documenting the route by taking pictures and making notes.
[54] Average speed: 1,6 km/h; Maximum speed: 6,3 km/h; Total time: 02:24:24; Cartographic length = 3,813 km. Again, the total time has to be corrected to approximately 90 minutes due to the above-mentioned reasons.
[55] Average speed: 3,5 km/h; Maximum speed: 5,6 km/h; Total time: 01:30:02; Cartographic length = 5,297 km. The total time has to be differentiated between circa 75 minutes downhill and circa 95 minutes uphill.

c) a well documented survey conducted by Austro-Hungarian officers in the year 1874, revealing that the route was still in use in the 19th century
d) a local tradition on the usage of the route in the 20th century (cf. the report given by Asen and Vanja Miluševi)

All these facts contribute to a picture, which leads us to the assumption that the route between Melnik and Zlatolist has its origin at least in the mediaeval period, although the written mediaeval sources do not attest this traffic relation explicitly. In order to expand further on this issue, "least-cost path" calculations will be incorporated into the study with the aim to create a computer based model.

I.5 On "least-cost path" modelling

The aim and function of "least-cost path" modelling is best explained by the following quotation from the secondary literature: "Archaeologists, however, often do not know the exact route of transportation links because for much of history transport did not involve the construction of specialised infrastructure such as roads and artificial waterways. Even where it did, such infrastructure may not have been preserved. Under these circumstances GIS [scilicet Geographic Information System] can be used to predict transport routes by deriving least-cost paths from an appropriate accumulated cost-surface. Of course, prediction of 'lost' routes is not the only use for least-cost paths: they can be compared to known routes in order to help understand the location of those routes."[56]

[56] James Conolly – Mark Lake, Geographical Information Systems in Archaeology. Cambridge 2006 (Cambridge Manuals in Archaeology), 252. A huge variety of literature has been published on the application of GIS and "least-cost path" modelling within the framework of archaeology, history and historical geography. Cf. for example: Pastor Fábrega Álvarez / César Parcero Oubiña, Proposals for an Archaeological Analysis of Pathways and Movement, *Archeologia e Calcolatori* 18 (2007), 121–140; Gino Bellavia, Predicting Communication Routes, in: John F. Haldon (Ed.), General Issues in the Study of Medieval Logistics. Sources, Problems and Methodologies. Leiden, Boston 2006 (History of Warfare, 36), 185–198; Daniel Arroyo-Bishop, GIS and Archaeology in France, *Archeologia e Calcolatori* 9 (1998), 31–45; Markus Breier, GIS in der Numismatik – Analysemethoden in der Interpretation von Fundmünzen. Wien 2009 (thesis, University of Vienna; can be downloaded via: http://othes.univie.ac.at/6480/, accessed 26 August 2010), 143 pages; Henry Chapman, Landscape Archaeology and GIS. Stroud 2006, 107–111; J. B. Claxton, Future Enhancements to GIS: Implications for Archaeological Theory, in: Gary Lock – Zoran Stančič (Eds.), Archaeology and Geographical Information Systems. London 1995, 335–348; Jim Crow – D. Mektav, Survey in Thrace August-September 2008, *Bulletin of British Byzantine Studies* 35 (2009), 51–55; François Djindjian, GIS Usage in Worldwide Archaeology, *Archeologia e Calcolatori* 9 (1998), 19–29; Kerstin Drosz, Zum Einsatz von Geoinformationssystemen in Geschichte und Archäologie, *Historical Social Research* 31/3 (2006), 279–287; Maurizio Forte – Sofia Pescarin, The Virtual Museum of Landscape, *Archeologia e Calcolatori* (2007), Supplemento 1, 87–99; Vince Gaffney – P. Martijn van Leusen, Postscript – GIS, Environmental Determinism and Archaeology, in: Gary Lock – Zoran Stančič (Eds.), Archaeology and Geographical Information Systems. London 1995, 367–382; Vince Gaffney – Helen Gaffney, Modelling Routes and Communications, in: Ewald Kislinger – Johannes Koder – Andreas Külzer (Eds.), Handelsgüter und Verkehrswege. Aspekte der Warenversorgung im östlichen Mittelmeerraum (4. bis 15. Jahrhundert). Wien 2010 (Veröffentlichungen zur Byzanzforschung, 18), 79–91; Ian N. Gregory – Paul S. Ell, Historical GIS. Technologies, Methodologies and Scholarship. Cambridge 2007 (Cambridge Studies in Historical Geography, 39); Stephen Kay – Timothy Sly, An Application of Cumulative Viewshed Analysis to a Medieval Archaeological Study: the Beacon System of the Isle of Wight, United

The model, which is to follow below (cf. part *II*), consists of a replication of the route between Melnik and Zlatolist – not of its prediction – in order to understand the reasons for its location.[57] This example of route was deliberately chosen, because it combines several factors suitable for "least-cost path" modelling.

Above all, it does not connect settlements on a plain, where infinite possibilities of routes can be calculated by a model. Both Melnik and Zlatolist are surrounded by terrain consisting of sandstone, which is changing constantly due to the impact of climate and which allows only a limited number of passages through the landscape (This circumstance, on the other hand, complicates the modelling to a certain extent, because the landscape today does not reflect the reality of mediaeval times).[58] Moreover, both the starting and the finishing position of the route – i.e. Melnik and Zlatolist – are known.

By combining all these factors and the available data, it becomes clear that the preconditions for a "least-cost path" model are completely fulfilled, because the "model is only as good as the input data and the ways in which those data are managed".[59] The working hypothesis henceforth addresses the following questions: If we recognise the route between Melnik and Zlatolist to be a connection used on a micro-level of transportation in the area in mediaeval and modern times, does this very route represent the ideal and best way between the starting and the finishing position? Did mediaeval men choose the shortest way, which needs the lowest expenditure of energy, or is there a more suitable alternative?[60] Will the route calculated by the "least-cost path" model be identical with the historically attested one?

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Kingdom, *Archeologia e Calcolatori* 12 (2001), 167–179; Martijn van Leusen, Viewshed and Cost-Surface Analysis using GIS (Cartographic Modelling in a Cell-Based GIS II), in: Juan A. Barceló – Ivan Briz – Asunción Vila (Eds.), New Techniques for Old Times. Oxford 1999 (BAR International Series, 757), 215–223; Marcos Llobera, Understanding Movement: a Pilot Model towards the Sociology of Movement, in: Gary Lock (Ed.), Beyond the Map. Archaeology and Spatial Technologies. Amsterdam 2000, 65–84; Barbara Pecere, *Viewshed* e *Cost Surface Analyses* per uno studio dei sistemi insediativi antichi: il caso della Daunia tra X e VI sec. A.C., *Archeologia e Calcolatori* 17 (2006), 177–213; Günter Prinzing, Elissos (Lezha) oder Kroai (Kruja)? Zu Anna Komnenes problematischer Beschreibung der mittelalbanischen Küstenregion zwischen Elissos und Dyrrachion (Durrës) um 1107, in: Klaus Belke – Ewald Kislinger – Andreas Külzer – Maria A. Stassinopoulou (Eds.), Byzantina Mediterranea. Festschrift für Johannes Koder zum 65. Geburtstag. Wien, Köln, Weimar 2007, 503–515; Zoran Stančič, GIS in Eastern Europe: Nothing New in the East?, *Archeologia e Calcolatori* 9 (1998), 237–249; Frank Vermeulen, Understanding Lines in the Roman Landscape: A Study of Ancient Roads and Field Systems Based on GIS Technology, in: Mark W. Mehrer – Konnie L. Wescott (Eds.), GIS and Archaeological Site Modelling. Boca Raton, London, New York 2006, 291–316; Konnie L. Wescott – R. Joe Brandon, Practical Applications of GIS for Archaeologists. A Predictive Modeling Toolkit. London 2000; David Wheatley – Mark Gillings, Spatial Technology and Archaeology. The Archaeological Applications of GIS. London 2002.

[57] Cf. on the replication and prediction of routes: Conolly – Lake, Geographical Information Systems, 255f.

[58] Cf. on the limits and problems of "least-cost path" modelling: Chapman, Landscape Archaeology, 107–111; Conolly – Lake, Geographical Information Systems, 252–255.

[59] Chapman, Landscape Archaeology, 107.

[60] Reasons for alternative ways could, for example, be places of worship or watering holes. The track between Melnik and Zlatolist offers both (i.e. the church of Sveta Petka and the church of Sveti Georgi with a well).

II. Terrain modelling and "least-cost path" determination

This part of the article presents the methodology used for the "least-cost path" determination between Melnik and Zlatolist. Section *II.1* shows the SRTM data used and the topographic surface surrounding Melnik. Section *II.2* presents a review on the theory of the applied algorithms. Sections *II.3* and *II.4* demonstrate the practical realisation within the GRASS GIS and the obtained results.

II.1 SRTM data and terrain modelling

The Shuttle Radar Topography Mission (SRTM), which produced the most complete, highest resolution digital elevation model (DEM) of the earth, was flown on the Space Shuttle Endeavour in February 2000 (STS-99) as a joint project of the *National Aeronautics and Space Administration* (*NASA*), the *National Geospatial Intelligence Agency* (*NGA*; the former *National Imagery and Mapping Agency* / *NIMA*) of the *US Department of Defense* (*DoD*) and the *Deutsches Zentrum für Luft- und Raumfahrt* (*DLR*). *DLR* worked in partnership with the *Agenzia Spaziale Italiana* (*ASI*). The SRTM objective was to acquire a digital elevation model of the earth between 60° north latitude and 56° south latitude, that is about 80% of the earth's land surface.[61] In quantitative terms the cartographic products deriving from the SRTM data were to be sampled over a grid of one arc-second by one arc-second (approximately 30 m by 30 m), with a linear vertical absolute height error of less than 16 m, a linear vertical relative height error of less than 10 m, a circular absolute geolocation error of less than 20 m and a circular relative geolocation error of less than 15 m. The relative height error of the X-band SRTM data was to be less than 6 m. All quoted errors are at 90% confidence level, consistent with the National Map Accuracy Standards (NMAS)[62]. These specifications are similar to those of the 30 m Digital Terrain Models (DTMs) produced by the *US Geological Survey* as part of the National Elevation Dataset.[63]

Radars at their most basic are instruments that measure only one dimension – the range from the radar to a target of interest. A radar instrument mounted on a moving platform can form two-dimensional measurements of a target location by exploiting the Doppler frequency shift of a given target as well as its range. This Synthetic Aperture Radar (SAR) technique yields two-dimensional images that are resolved in range proportional to the reciprocal of the radar bandwidth and in azimuth equal to half the antenna length in the direction of motion. To access the third dimension, a range difference between two radar images is required, and this is realised most accurately and efficiently using the principles of interferometry.[64] The radar is a phase-coherent imaging system, and the phase of the radar signal encodes the path distance to the surface and back as well as any phase imparted by backscatter

[61] Tom Farr et al., The Shuttle Radar Topography Mission, *Reviews of Geophysics* 45 (2007), 1–33.
[62] Cf. on these standards: http://egsc.usgs.gov/isb/pubs/factsheets/fs17199.html (accessed 17 August 2010).
[63] Dean Gesch et al., The National Elevation Dataset, *Photogrammetric Engineering & Remote Sensing (Journal of the American Society for Photogrammetry and Remote Sensing)* 68/1 (2002), 5–11.
[64] Farr et al., The Shuttle Radar Topography Mission, passim.

from the surface. If the images from two antennas are acquired simultaneously and from close enough vantage points, the backscatter phase observed in both images from each point on the ground will be the same. The phase difference between each image point will then simply be the path difference between the two measurements of the point. Assuming the position of the two antennas (the "interferometric baseline") is known, the dimensions of the interferometric triangle can be determined accurately, and so also the height of a given point.

II.1.1 SRTM based terrain modelling for the region of Melnik

In order to calculate the "least-coast path" between Melnik and Zlatolist, the scene 41-04 from the SRTM dataset was used. Only a cut surrounding the region was utilised for this step. The original 90 m resolution image was not suitable to build an optimal pathvisualisation, since the least-cost algorithms are raster based. In order to overcome this issue, the data was resampled into a 5 m resolution grid by splitting each SRTM pixel in 324 tiles and determinating the Z value for each tile (a 5 m pixel) with the inverse of distance interpolator. Figure 27 shows the original SRTM data (a) and the refined DTM (b).

II.2 "Least-cost path" determination

Within Geographic Information System (GIS) packages solutions for "least-cost path" determination are found using a family of algorithms known as Accumulated Cost Surface (ACS) methods. The ACS procedures are applied to raster datasets, in which the input surface is a grid of generalised costs, i.e. every cell is assigned a cost measure – providing a gridded representation of the cost surface highlights the importance of using a sufficiently fine representation of the surface, since the solution path must be computed by adding up the costs along alternative paths. For this reason, the original SRTM dataset was refined to a 5 m resolution DTM, as shown above in section *II.1.1*. The next sections explain the principles for accumulated and friction surfaces determination, the core steps for an accurate low-cost path determination. Figure 28 illustrates an example of the difference between a short but hard path and a long, easy path.

II.2.1 Accumulated surfaces

Accumulated surfaces are raster models that allow the calculation of a "least-cost path" from a point "A" (start) to a point "B" (target). The term "accumulated" implies that there is a building up of numbers or values. The cost for a cell in an accumulated surface is a value that represents a cumulative cost from the target. For example, in order to travel across four cells in a row with the first two cells each having a value of one and the second two cells each having a value of two, the accumulated cost to travel through the four cells is six; and this value is stored in the start cell. Under normal conditions the values must increase the further away you get from the point of origin.[65]

[65] Chistopher W. Stahl, Accumulated Surfaces & Least-Cost Paths: GIS Modeling for Autonomous Ground Vehicle (AGV) Navigation. Thesis submitted to the faculty of the

II.2.2 Friction surfaces

Friction surfaces contain no cumulative values, but costs from which the accumulated surface is created. Friction surfaces are a significant factor in developing realistic accumulated surfaces. Friction surfaces are matrices that add resistance to travel within the matrix.

According to Burrough and McDonnel, friction is "the attribute of the cells through which distance accumulation take place".[66] Different friction layers can be combined into one to perform an anisotropic type of modelling. Anisotropic is opposite of isotropic, therefore cost values are not equal on axes of all directions. Some frictions that can aid in anisotropic modelling are wind, slope, fuel consumption, monetary expense, risk, or any other variable that can inhibit travel. Generally, this type of accumulation is best for modelling real world situations, in which travel is complex and involves many decisions.

In order to achieve good results from a GIS model, it must contain all the factors that would play a role in the movement. The most efficient means of travel, the "least-cost path", is the guide between the origin and the destination. It is vital that the accumulated surface represents as far as possible real conditions or costs. Real conditions can be modelled best with anisotropic surfaces or algorithms.

The most popular algorithm used for routing applications is the Dijkstra algorithm. This algorithm accumulates all cells with a distance equal from the origin to the target. The accumulation process starts from the target and works its way outward. In figure 29 the pink cell represents a starting point and the purple cell is the path end. From the starting point the algorithm examines each cell in order of distance from the start and will iteratively search for the next closest cell. For every cell travelled from the starting point, cost increases until the finishing point is found. The cells in dark cyan represent cells of lower cost than those brighter.[67]

II.3 "Least-cost path" with GRASS GIS

The GRASS GIS package was chosen for the processing of the Melnik model data, since it is the most advanced open-source GIS.[68] Within GRASS, the "least-cost path" determination comprises three steps on the basis of the Dijkstra algorithm: *r.cost*, *r.walk* and *r.drain*. These steps are explained in the following sections.

II.3.1 r.cost

The first step, *r.cost*, determines the cumulative cost of moving to each cell on a cost surface from the start cell, whose location is specified by its geographic

Virginia Polytechnic Institute and State University. Blacksburg/Va. 2005, passim. This unrestricted thesis can be downloaded via: http://scholar.lib.vt.edu/theses/available/etd-05262005-151814/unrestricted/thesisfinal.pdf (accessed 18 August 2010).

[66] Peter A. Burrough – Rachael A. McDonnell, Principles of Geographical Information Systems. Oxford 1998, 352.

[67] Stahl, Accumulated Surfaces, 23ff.

[68] Cf. on GRASS GIS in detail: http://grass.osgeo.org/ (accessed 17 August 2010).

coordinates. Each cell in this first cost surface map will contain a value which represents the cost of traversing that cell. *r.cost* produces an image, in which each pixel (or cell) contains the lowest total cost of traversing the space between each cell and the starting point.[69] This step uses as basis the refined SRTM DTM of the Melnik region (cf. figs. 27a and 27b). Two cost surfaces were determined: one from Melnik to the Pass (Goljam Ključ) and the other from Zlatolist to the Pass (Goljam Ključ). The reasons for this split are explained in section *II.3.2*.

II.3.2 r.walk

r.walk outputs an image showing the lowest cumulative cost of moving between each cell and the starting points (Melnik or Zlatolist). It uses an input elevation image, whose pixels represent elevation, combined with a second input raster map layer, whose pixels represent friction costs. This step is similar to *r.cost*, but in addition to a friction map, it considers an anisotropic travel time due to the different walking speed associated with downhill and uphill movements.[70]

The formula by Langmuir[71] has been used to estimate the cost parameters of specific slope intervals:

T= [(a)*(Delta S)] + [(b)*(Delta H uphill)] + [(c)*(Delta H moderate downhill)] + [(d)*(Delta H steep downhill)]
where:
T is the time of movement in seconds.
Delta S is the distance covered in meters.
Delta H is the altitude difference in meters.

The parameters a, b, c and d take into account movement speed in the different conditions and are linked to:

a: underfoot condition (a=1/walking_speed)
b: underfoot condition and cost associated to movement uphill
c: underfoot condition and cost associated to movement moderate downhill
d: underfoot condition and cost associated to movement steep downhill

It has been proved that moving downhill is favourable up to a specific slope value threshold, after that it becomes unfavourable. Within GRASS GIS the default slope value threshold (slope factor) is -0.2125, corresponding to tan(-12), calibrated on human behaviour (>5 and <12 degrees: moderate downhill; >12 degrees: steep downhill). The default values for a, b, c and d are those proposed by Langmuir:

a = 0.72 ; b = 6.0 ; c = 1.9998 ; d = -1.9998

[69] Cf. http://www.grass.itc.it/grass62/manuals/html62_user/r.cost.html (accessed 18 August 2010).
[70] Cf. http://www.grass.itc.it/grass62/manuals/html62_user/r.walk.html (accessed 18 August 2010).
[71] Eric Langmuir, Mountaincraft and Leadership: a Handbook for Mountaineers and Hillwalking Leaders in the British Isles. Manchester ^{3}2004, passim.

These values were determined based on a man's walking effort in standard conditions. Nevertheless, empirical tests in this work have revealed that this modelling only shows good results for uphill paths. For this reason, the way from Melnik to Zlatolist was split into two parts: from Melnik to the Pass and from Zlatolist to the Pass. The Pass position was automatically determined (cf. figs. 31 and 32).

Fig. 31: The "least-cost path" between Melnik and the Pass (in yellow); © 2009 Google, © 2010 Tele Atlas, © 2010 Europa Technologies, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Juilson J. Jubanski

Fig. 32: The "least-cost path" between Zlatolist and the Pass (in yellow); © 2009 Google, © 2010 Tele Atlas, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Juilson J. Jubanski

The lambda parameter of the linear equation combining movement and friction costs must be set in the option section of *r.walk*.

total cost = movement time cost + (lambda) * friction costs

For a more accurate result the "knight's move" option has been used in this work.[72] The minimum cumulative costs are then computed using Dijkstra's algorithm, which finds an optimum path between the given points (see section *II.3.1*).

Once *r.walk* computes the cumulative cost map as a linear combination of friction cost (from the friction map) and the altitude as well as distance covered (from the digital elevation model), the last step called *r.drain* can be used to find the "least-cost path".

II.3.3 r.drain

r.drain traces a "least-cost path" in the elevation model.[73] The input are an elevation surface and the cumulative cost map generated by the *r.cost* step. The result shows the "least-cost path" between the starting point (Melnik or Zlatolist) and the finishing point [the Pass (Goljam Ključ)].

As can be seen in fig. 27b, the refined DTM is very smooth. As a consequence, the algorithm traced a path through the cliffy areas on the southern borders of Melnik (to the south of the high ground Sveti Nikola, cf. fig. 1). In order to overcome this issue, the cliffy area was manually digitised and its cumulative cost was set to infinity. Figures 30a and 30b show the final cumulative cost maps for the two determined paths. Blue means lower costs and red values higher costs. The cliffy area is marked with dark-red colour.

II.4 Results

Figure 31 presents the "least-cost path" from Melnik to the Pass (in yellow). The turquoise route is the GPS track recorded on 16 June 2010 (cf. *I.3*). As described above, the red zone is the cliffy area to the south of Melnik. The differences between both tracks (about 100 m) can be explained by the SRTM data resolution (90 m) and its altimetric precision (about 10 m).

Figure 32 shows the "least-cost path" from Zlatolist to the Pass (in yellow), whereas the turquoise route is the GPS track recorded on 16 June 2010 (cf. *I.3*). Again, the red coloured zone represents the cliffy area to the south of Melnik. The differences between both tracks (about 100 m) are caused by the SRTM data resolution (90 m) and its altimetric precision (about 10 m). The most remarkable difference can be recognised immediately to the south of the Pass (Goljam Ključ), on the southern versant towards Zlatolist. Finally, figure 33 illustrates the complete "least-cost path" (in yellow) between Melnik and Zlatolist.

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[72] Also cf. Stahl, Accumulated Surfaces, 22. The "knight's move" algorithm uses 16 neighbours (one step up and one diagonal) in its calculations.

[73] Cf. http://www.grass.itc.it/grass62/manuals/html62_user/r.drain.html (accessed 18 August 2010).

Fig. 33: The complete “least-cost path” between Melnik and Zlatolist (in yellow); © 2009 Google, © 2010 Tele Atlas, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Juilson J. Jubanski

III. Summary

The combination of all aspects of this study enables us to draw the following conclusions. Above all, the calculated “least-cost path” confirms the usefulness of the historically attested route between Melnik and Zlatolist. It shows without doubt that the easiest and most direct way between these two points went and still goes via the pass Goljam Ključ. This again means that mediaeval men were well aware of the nature of the topographical conditions in the surrounding area of Melnik and of their own capabilities.

Still, there are some aspects to be discussed and explained on the basis of the presented model. The fact that the cumulative cost of the cliffy area to the south of the high ground Sveti Nikola was set to infinity within the model reflects the reality of today’s topography. Neither is it possible to descend from the high ground Sveti Nikola directly to the south nor to cross through a valley to the south of the high ground from west to east, because it is totally blocked by erosion. Both alternatives of passage can be excluded on the basis of field research conducted in 2007 as well as 2010.

If we take a look at the first part of the route between Melnik and the Pass (cf. fig. 31), we realise a slight difference between the existing route (in turquoise) and the calculated “least-cost path” (in yellow). This difference (about 100 m) can be explained on the one hand by the SRTM data resolution (90 m) and its altimetric precision (about 10 m). Additional (but cost-intensive) data gained on the basis of Light Detection and Ranging (LIDAR), airborne Synthetic Aperture Radar (SAR) and TerraSAR-X would help to enhance the existing model. On the other hand we do see that the “least-cost path” tends to follow either the feet or the ridges of the sandstone cliffs (both marked with pink rectangles in fig. 34), which would indeed be the ideal way from the viewpoint of computer based calculations, but at this point does neither take into account the geological preconditions on a micro-level, which cannot be reflected by the SRTM data resolution, nor the difficulties as well as the effort needed to pass through the dense vegetation cover in these zones.

In the second part of the route between the Pass and Zlatolist the most remarkable difference between the existing route (in turquoise) and the calculated “least-cost path” (in yellow) can be discerned immediately to the south of the Pass (Goljam Ključ) (marked with pink rectangles in fig. 35). Field research revealed that the computer based calculations prefer a direct way, leading south through a hollow, which could be used by a human being with difficulty, but not by pack-animals due to the slope and the dense vegetation cover. That is why the existing route leads slightly to the east and then turns south in order to neutralise the slope in this zone. Finally, we recognise a marginal difference between both routes in the grass-grown valley towards Zlatolist, which can be ignored completely, because the terrain is flat and allows smooth movement in the middle of the valley as well as on its edges at the feet of the sandstone cliffs.

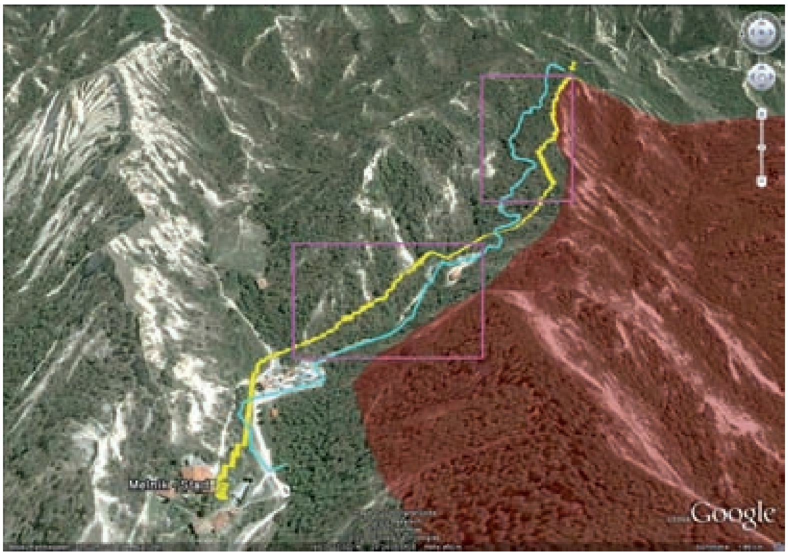

Fig. 34: Differences between the existing route (in turquoise) and the calculated “least-cost path” (in yellow) on the northern versant; © 2009 Google, © 2010 Tele Atlas, © 2010 Europa Technologies, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Juilson J. Jubanski

Fig. 35: Differences between the existing route (in turquoise) and the calculated “least-cost path” (in yellow) on the southern versant; © 2009 Google, © 2010 Tele Atlas, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Juilson J. Jubanski

To sum up, it has to be stressed that this article presents a pioneer work, not only within the project "Macedonia, Northern Part" (Mihailo Popović, *TIB* 16)[74], but also within the overall project *TIB* of the Austrian Academy of Sciences, both under the supervision of Prof. Dr. Johannes Koder, as well as within the field of Byzantine Studies.[75] It breaks new scientific ground by combining for the first time data on the historical geography of the Byzantine Empire, deriving from written sources and archaeology, with unpublished, i.e. unknown, archive material from the 19th century preserved in Viennese archives as well as applications of GPS and GIS ("least-cost path").

This case study on the route Melnik-Zlatolist reveals the continuity of transportation on a micro-level through mediaeval and modern times by applying the means of replication within a "least-cost path" model. It proves that the framework of the historically attested and today still existing route established by men matches for the most part the computer based calculations via GIS. The usefulness of the utilised method will be repeated on selected case studies from the historical region of Macedonia in the near future in order to enrich the scientific research of the *TIB*.

Vorgelegt von w.M. Johannes Koder
in der Sitzung am 17. Dezember 2010

[74] Cf. http://www.oeaw.ac.at/byzanz/tib014.htm (accessed 20 August 2010).

[75] Rare are the examples of GIS-applications within Byzantine Studies, its only experienced proponent being Prof. Dr. Vince Gaffney (Birmingham). Cf. on his publications in this field: Gaffney – Gaffney, Modelling Routes, 86f.

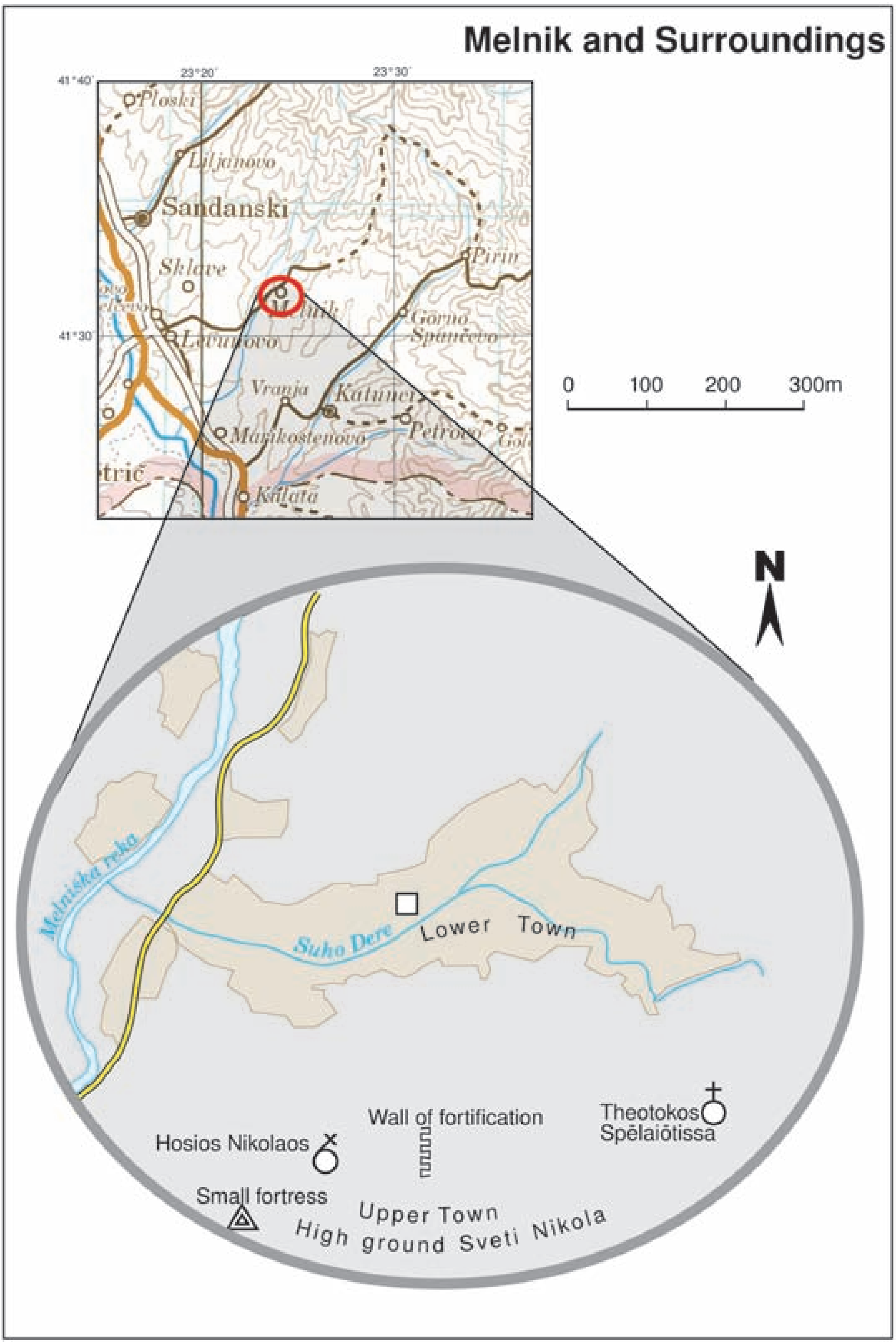

Fig. 1: Melnik and its surrounding area; designed by Elisabeth Ch. Beer

Fig. 2: The sandstone cliffs surrounding the town of Melnik; Mihailo St. Popović (*TIB* 16)

Fig. 3: Melnik's neighbouring towns and villages; designed by Mihailo St. Popović

Fig. 4: Sketch of the route between Melnik and Zlatolist drawn by Vanja Miluševa; Mihailo St. Popović

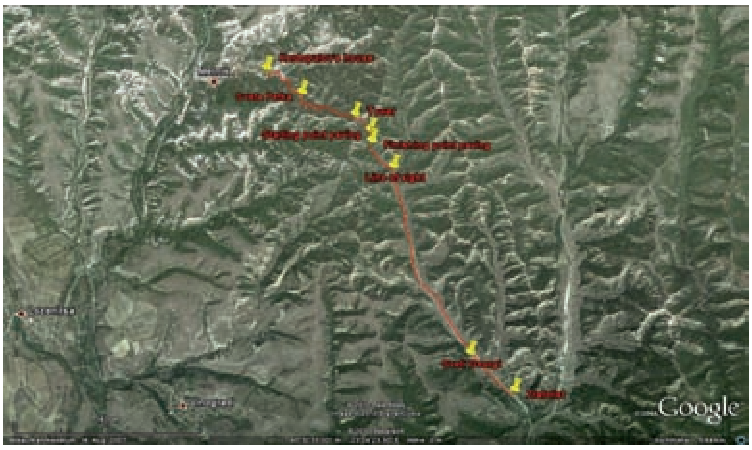

Fig. 6: The survey's GPS-waypoints recorded in 2007 and 2010; © 2009 Google, © 2010 Tele Atlas, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML (Keyhole Markup Language) layer by Mihailo St. Popović

Fig. 7: Kordopulov's house from the south-west; Mihailo St. Popović (*TIB* 16)

Fig. 8: The church of Sveta Petka from the south-east; Mihailo St. Popović (*TIB* 16)

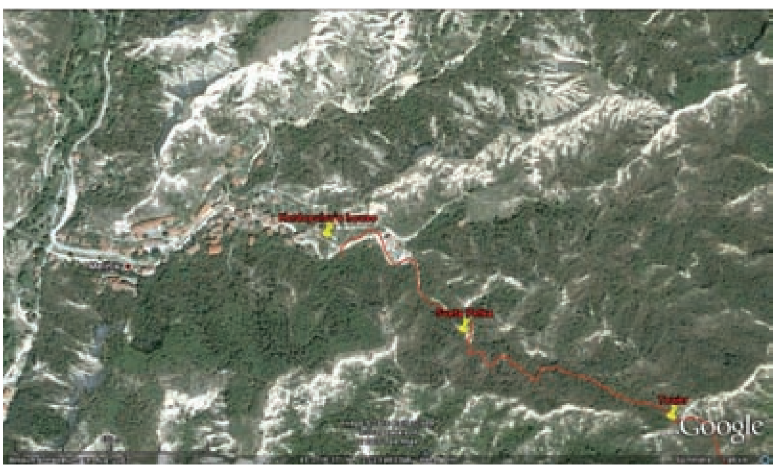

Fig. 9: Detail of the survey's GPS-waypoints on the northern versant towards Melnik; © 2009 Google, © 2010 Tele Atlas, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Mihailo St. Popović

Fig. 10: The church of Sveta Petka in the foreground (1), Kordopulov's house in the background on the right (2), the monastery Theotokos Spēlaiōtissa in the background on the left (3); Mihailo St. Popović (*TIB* 16)

Fig. 11: The church of Sveta Petka, structures from the 6th century AD (?); Mihailo St. Popović (*TIB* 16)

Fig. 12: Dense vegetation on the northern versant of the route; Mihailo St. Popović (*TIB* 16)

Fig. 13: Looking from the northern versant in the direction of Melnik, the church of Sveta Petka in the foreground (1), Kordopulov's house in the background (2); Mihailo St. Popović (*TIB* 16)

Fig. 14: The southern exit of the pass Goljam Ključ; Mihailo St. Popović (*TIB* 16)

Fig. 15: The remnants of the tower at Goljam Ključ; Mihailo St. Popović (*TIB* 16)

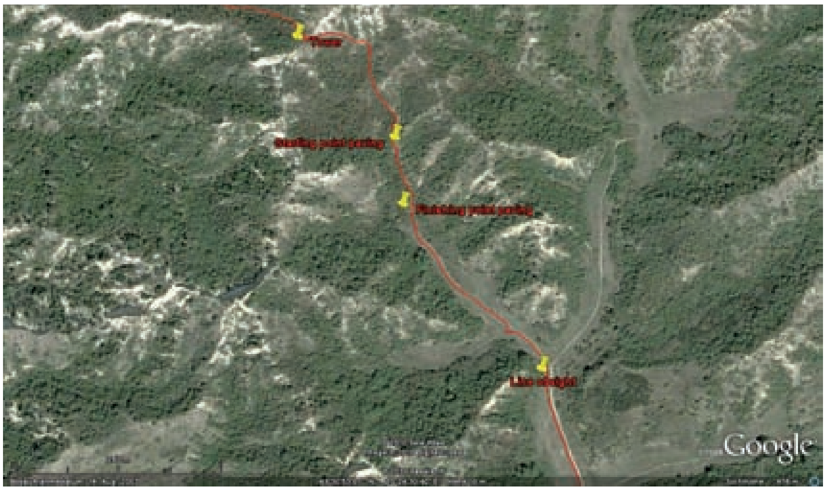

Fig. 16: The line of sight to the tower at Goljam Ključ visualised by GPS-waypoints; © 2009 Google, © 2010 Tele Atlas, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Mihailo St. Popović

Fig. 17: The line of sight to the tower at Goljam Ključ, in the foreground resting places financed by the European Union; Mihailo St. Popović (*TIB* 16)

Fig. 18: The starting point of the paving on the southern versant towards Zlatolist; Mihailo St. Popović (*TIB* 16)

Fig. 19: The finishing point of the paving on the southern versant towards Zlatolist; Mihailo St. Popović (*TIB* 16)

Fig. 20: The valley leading to the village of Zlatolist; Mihailo St. Popović (*TIB* 16)

Fig. 21: Detail of the survey's GPS-waypoints on the southern versant towards Zlatolist; © 2009 Google, © 2010 Tele Atlas, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Mihailo St. Popović

Fig. 22: The church of Sveti Georgi from the north-east; Mihailo St. Popović (*TIB* 16)

Fig. 23: The village of Zlatolist; Mihailo St. Popović (*TIB* 16)

Fig. 24a: Drawing of the expedition conducted by Austro-Hungarian officers on 19 June 1874; Österreichisches Staatsarchiv (Vienna, Austria), Kriegsarchiv, B III c 19-04, Blatt XXX

Fig. 24b: Drawing of the expedition conducted by Austro-Hungarian officers on 19 June 1874 (detail), church of Sveti Georgi (1); Österreichisches Staatsarchiv (Vienna, Austria), Kriegsarchiv, B III c 19-04, Blatt XXX

Fig. 25: The village of Pirin from the south; Mihailo St. Popović (*TIB* 16)

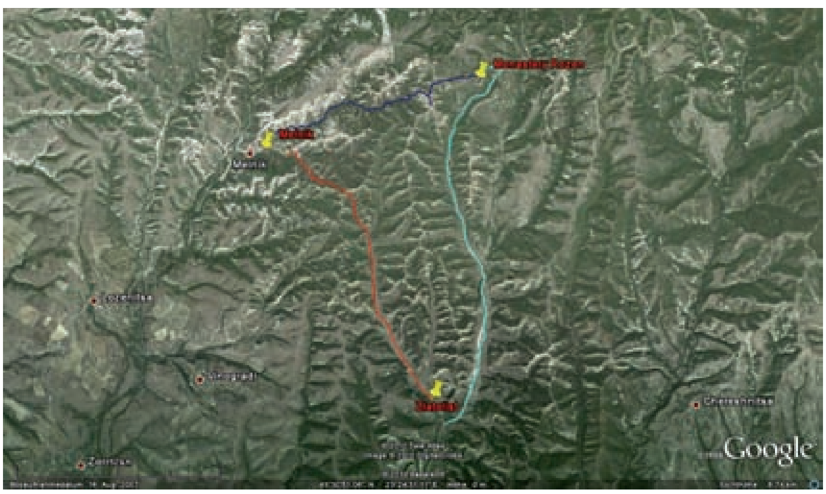

Fig. 26: The three GPS-routes in the triangle Melnik-Rožen-Zlatolist; © 2009 Google, © 2010 Tele Atlas, Image © 2010 DigitalGlobe, © 2010 Basarsoft; KML layer by Mihailo St. Popović

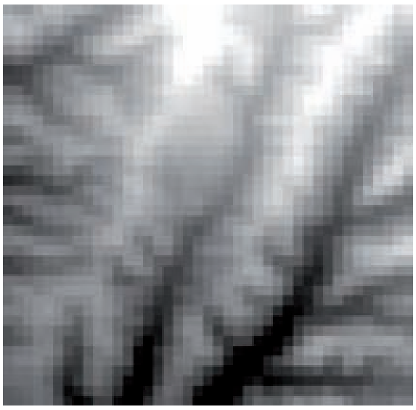

Fig. 27a: Original SRTM Data; Juilson J. Jubanski

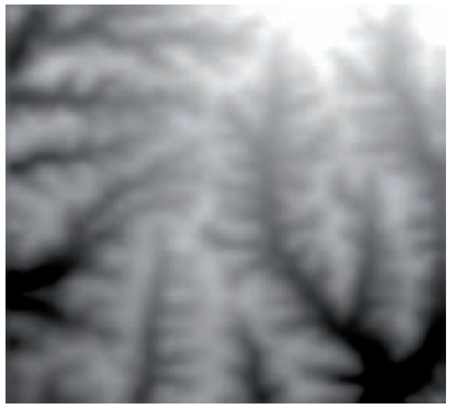

Fig. 27b: Refined DTM; Juilson J. Jubanski

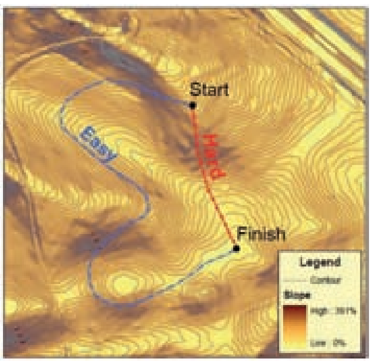

Fig. 28: Hard and easy path examples; Stahl, Accumulated Surfaces, 21 [on the basis of: http://theory.stanford.edu/~amitp/GameProgramming/ (accessed 20 August 2010)]

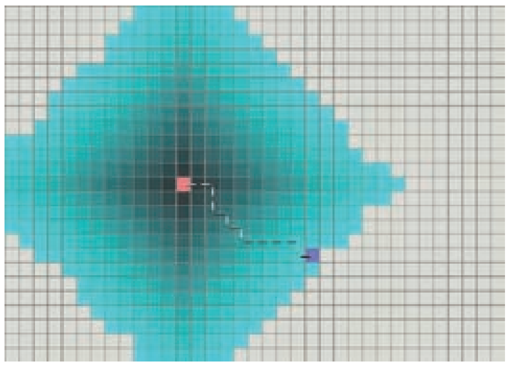

Fig. 29: Least-cost with the Dijkstra algorithm; Stahl, Accumulated Surfaces, 24 [on the basis of: http://theory.stanford.edu/~amitp/GameProgramming/ (accessed 20 August 2010)]

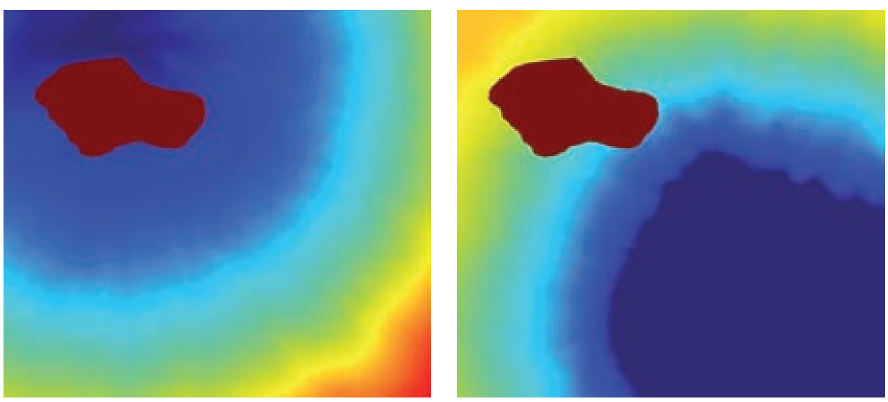

Fig. 30: Cumulative cost maps (a) Melnik (b) Zlatolist; Juilson J. Jubanski