GEODETICAL AND ASTRONOMICAL ASPECTS OF KRAKOW'S PREHISTORIC MOUNDS

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1. INTRODUCTION

In the eastern part of Krakow area two prehistoric mounds are located: Krakus mound (KR) and Wanda mound (KW). Both the origins and purposes of the mounds have been so far unexplained. Legends and theories that are neither confirmed nor rejected by archaeological research have grown around them. Krakus mound (16 metre high with base diameter of 60 meters) is situated in Podgórze District atop Lasota Hill. According to the legend it is a burial mound of the founder of Krakow: King Krak. Currently used name of the mound Krakus comes from that legendary King, Fig. 1 and 3.
One of the hypotheses claims that the mound was raised by the Celts in the 2nd or 1st century BC. However, the objects found during the archaeological research would rather suggest that the mound was raised between the 8th and 10th century AD.

Wanda mound is situated in the District of Nowa Huta. It is 15.5 metre high with about 50 metres in diameter at the base. According to the legend it is a burial mound of Princess Wanda, the daughter of King Krak, Fig. 2 and 4.

For our purposes one more mound, the so called Krak mound (KK) located in Krakuszowice, is also interesting. It is about 22.7 km south-east of Krakus mound. According to the legend it is a burial mound of King Krak's son, whose name is also Krak, Fig. 6. These three legendary „family" mounds determine three directions, which are interesting from astronomical point of view.

Fig. 1. Krakus mound. Photo: W. Góral

Fig. 2. Wanda mound. Photo: W. Góral

Fig. 3. View of Krakus mound from Wanda mound . Photo: W. Góral

Fig. 4. View in direction of Wanda mound from Krakus mound. Photo: W. Góral

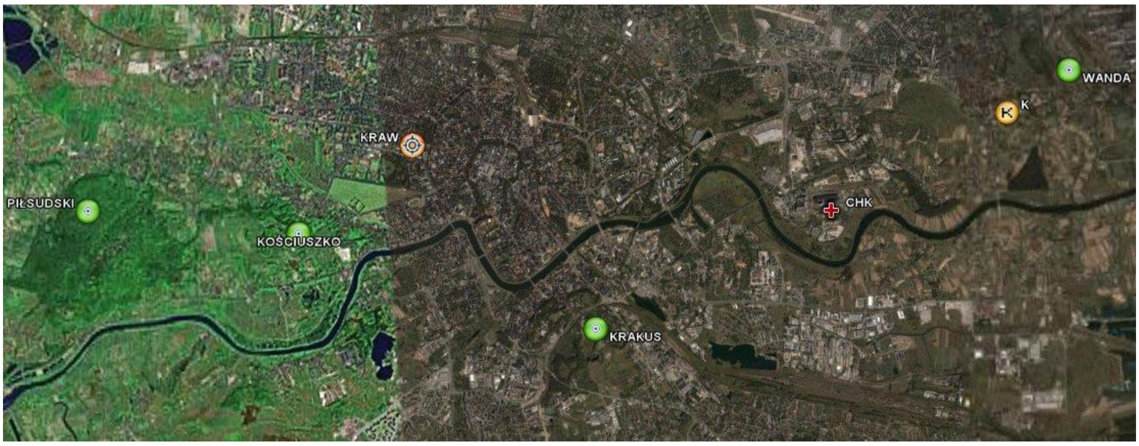

Fig. 5. Krakow's mounds from the Google Earth, KRAW – GPS permanent station in Krakow

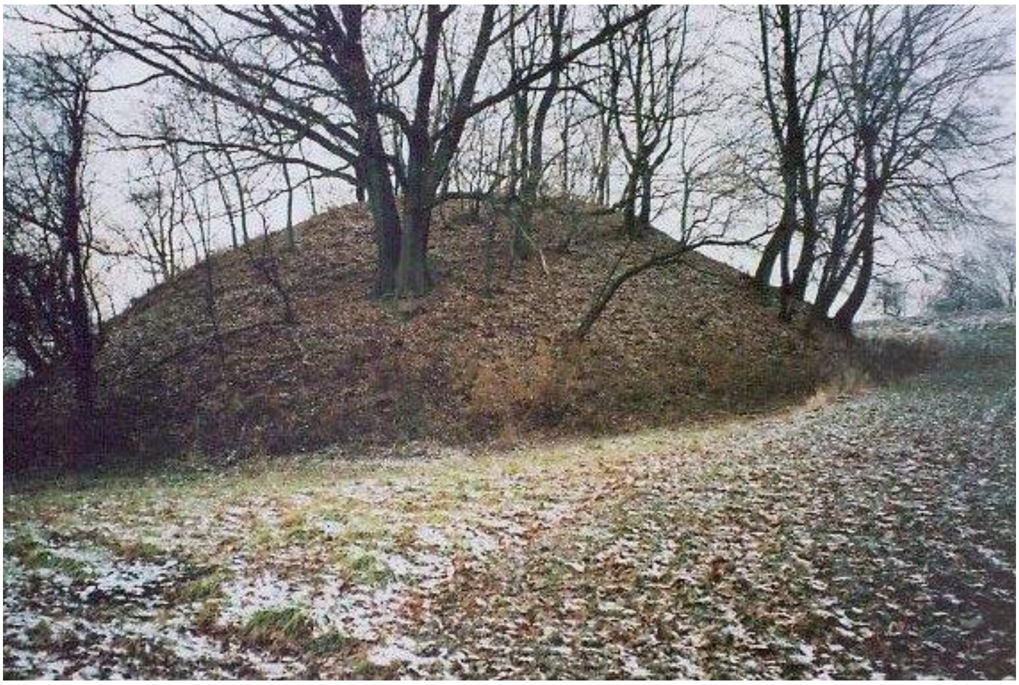

Fig. 6. Krak mound in Krakuszowice. Photo W. Góral

Moreover, in the landscape of Krakow there are Kosciuszko mound (KO) – 34-metre-high, build in 1820-1823 and Pilsudski mound (PI) – apr. 34-metre-high, build in 1934-1937, Fig.: 7, 8, 9. The above mentioned mounds are well seen from space with the help of Google Earth, Fig. 5.

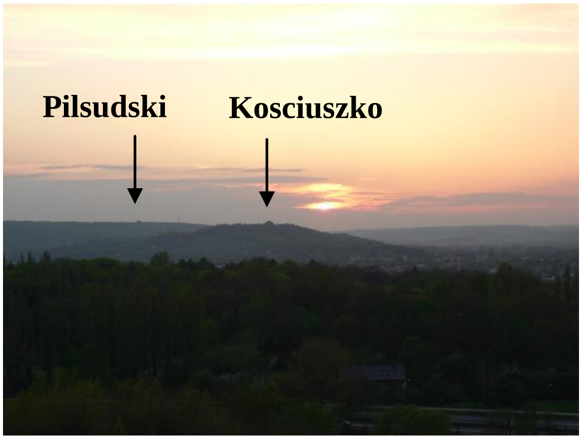

Fig. 7. Kosciuszko mound and Pilsudski mound. General view of western horizon as seen from Krakus mound. Photo: W. Góral

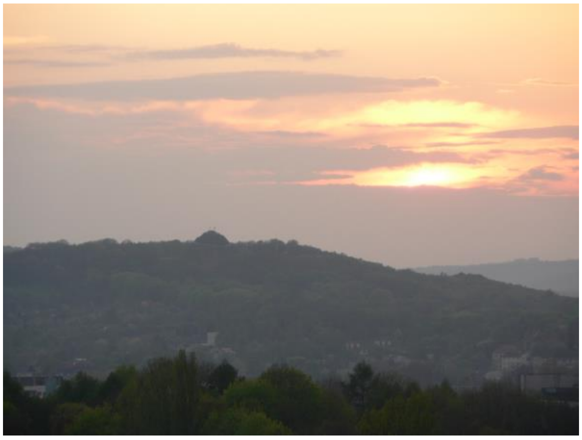

Fig. 8. Kosciuszko mound. View of Kosciuszko mound from Krakus mound. Photo: W. Góral

Fig. 9. Sunset 27-04-2006, wiew of Kosciuszko mound from Krakus mound. Photo: W. Góral

2. ALIGNMENTS THROUGH THE MOUNDS: KRAKUS, WANDA AND KRAK

In Table 1 geodetical coordinates(φ, λ, h) determined on the basis of GPS observations are given.

Table 1

Point	φ [°′″]	λ [°′″]	h (H) [m]	Point name
KR	50 02 17	19 57 30	309.2 (269.4)	Krakus mound
KW	50 04 13	20 04 05	277.9 (238.5)	Wanda mound
KK	49 57 01	20 14 39	----	Krak mound
KO	50 03 18	19 53 36	366.3 (326.3)	Kosciuszko mound
PI	50 03 36	19 50 50	423.1 (383.0)	Piłsudski mound
WA	50 03 17	19 56 06	332.6 (292.8)	Wawel Hill
W297	49 58 31	20 09 26	336.1 (297.0)	Triangle marker

The above coordinates made it possible to calculate the distance (d) and azimuth (A) between two given points. Having the azimuth of a given direction, on the base of formula (1), one can calculate the declination (δ) of the Sun or Moon in the horizon, when they rise or set.

$$\sin\delta = \cos\varphi \; \cos A \qquad (1)$$

Declination of the Sun can also be calculated from the formula:

$$\sin\delta = \sin\varepsilon \; \sin\lambda_S \qquad (2)$$

where $\varepsilon = 23^{o}26'19''$(2005.5) is the obliquity of the ecliptic, λ_S is the celestial longitude of the Sun, measured in the plane of the ecliptic from vernal equinox.
When declination of the Sun is known, one can obtain the date of sunrise or sunset for a given place of known latitude φ (Table 2).

Table 2

	Direction	Dist. d[m]	A_{1-2} [°′″]	A_{2-1} [°′″]	δ [°′]	Date Sunrise		Date Sunset	
1	KR-KW	8629	65 29 38	245 34 41	15 28	2.V	10.VII	6.II	4.XI
2	KR-KK	22703	115 21 00	295 34 08	-16 01	4.II	6.XI	5.V	9.VIII
3	KW-KK	18366	136 29 00	316 37 06	-27 47	---	---	---	---
4	KR-WA	2492	317 57 27	137 56 23	28 31	---	---	---	---
5	PI - KR	8335	107 0 24	287 05 31	-10 50	20.II	21.X	18.IV	24.VIII
6	KR-W297	15 881	116 06 32	------------	------	------	-------	------	------
7	KO -KR	5015	111 54 57	291 57 56	-13 53	11.II	30.X	27.IV	15.VIII
8	KO-KW	12618	82 11 31	262 19 33	5 01	2.IV	9.IX	7.III	5.X
9	KO-WA	2981	90 25 24	270 27 19	-0 01	20.III	22.IX	20.III	22.IX
10	PI-KW	15860	85 49 51	266 00 01	2 41	27.III	15.IX	13.III	29.IX

The lines KR-KW and KR-KK form interesting solar alignments. The direction KR-KW indicates two positions of sunrise, which take place roughly in the middle of spring equinox and summer solstice and then in the middle of summer solstice and autumn equinox. On the other hand the opposite direction KW-KR indicates two positions of sunset which take place in the middle of the autumn equinox and winter solstice and then in the middle of winter solstice and spring equinox. Also alignment KR-KK point the sunrise and in the opposite direction the sunset on four days of the year that are roughly midway between the solstices and equinoxes: on 6 November, 4 February, 5 May and 9 August.

The azimuth of the direction KR-S_1 (KR-KW) is $65^0\,30^{'}$. On this alignment the sun rises on 2 May and 10 August. In these days the Sun sets in the direction KR-S_{11} with the azimuth bearing, Fig. 10

$$A_{11} = 360^0 - A_1 \quad (3)$$

In opposite direction KR-S_{31} (KW-KR) the Sun sets on 6 February and 4 November with the azimuth

$$A_{31} = 180^0 + A_1 \quad (4)$$

In these days sunrise takes place on the bearing KR-S_3 with azimuth

$$A_3 = 180^0 - A_1 \quad (5)$$

Similarly, as Tab. 2. p.2 shows the azimuth bearing KR-KK (KR-S_3) is $115^0 21'$. On this bearing the Sun rises (Tab. 2. p.2) on 4 February and 6 November and sets in the opposite direction KR-S_{11} on 5 May and 9 August. These dates are roughly midway between the solstices and equinoxes and coincide with the main Celtic feasts. In a year apparent motion of the Sun circles the ecliptic and its ecliptic longitude varies in the range $0^0 \leq \lambda_S < 360^0$. As a result of this motion one can observe the movement of points of sunrises (sunsets) from Krakus mound in the plane of the horizon in sectors S_2-S_4 and sunsets in sector S_{21}-S_{41} (Fig. 10).

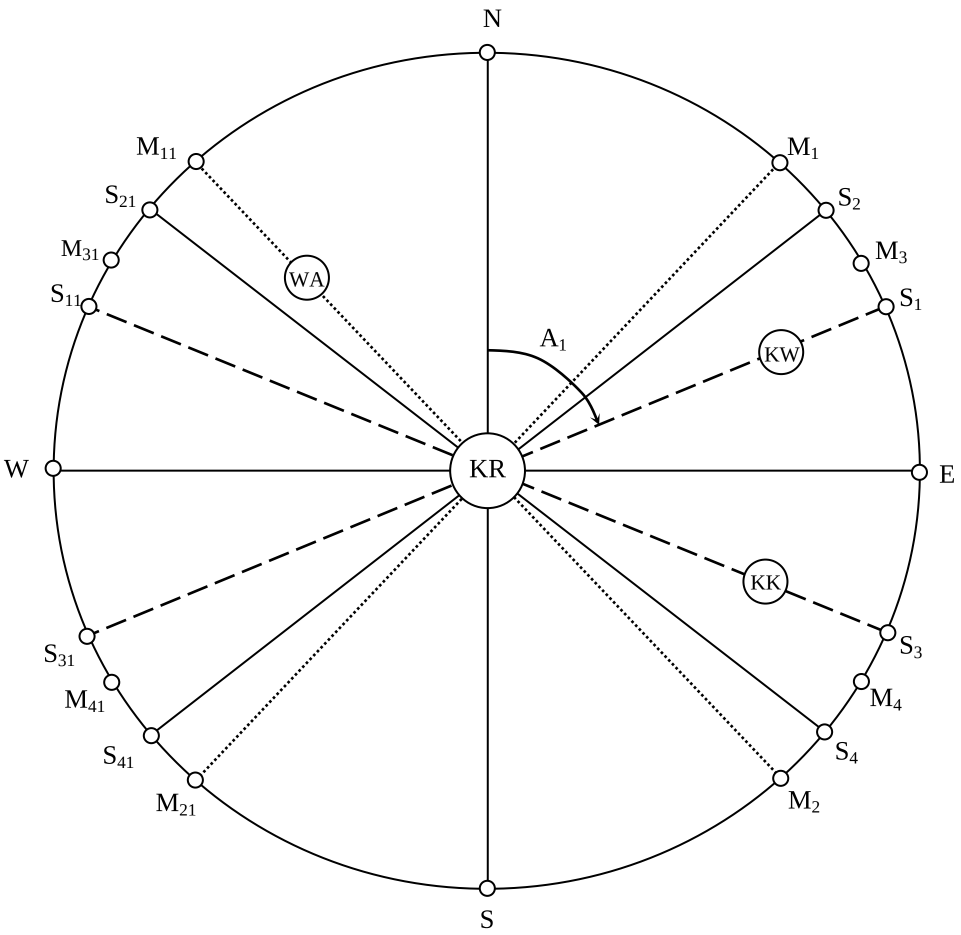

Fig. 10. Sun and Moon alignments from Krakus mound

Because the declination of the Sun ranges $-\varepsilon \leq \delta \leq \varepsilon$, the Sun's apparent position both in the sky and in the horizon change in an annual cycle. The Moon has a cycle 18.6 years in its position in the sky and in the horizon. In the above period the Moon's declination varies in the range $-\varepsilon - i \leq \delta_M \leq \varepsilon + i$, where $i = 5^0 08'43''$ is the orbital inclination of the Moon to the ecliptic plane. As a result of this motion one can observe the movement of points of moonrises (moonsets) from the Krakus mound in the plane of the horizon in sectors M_1-M_2 and moonsets in sector M_{11}-M_{21} (Fig. 10).
For the sake of comparison of four above mentioned azimuths of sunrises (sunsets) we shall calculate their theoretical values in the funtion of $\lambda_{S.}$ Comparing azimuth bearing KR-KW with their theoretical value for $\lambda_S = 45^0$, we obtaine the difference (O-C) $\Delta A = 1^0 27'$, and for direction KR-KK $\Delta A = -0^0 36'$. The results prove that the position of three mounds: Krakus, Wanda and Krak are not haphazard.

Prof. Kotlarczyk (Kotlarczyk, 1979) connected the sunrise in the direction KR-KW with the Celtic festival of Beltane (appr. 1 May). Moreover Prof. Kotlarczyk discovered a couple of mounds in Solca and Komarowice near Przemysl (more than 200 km east of Krakow). The above mounds of azimuth bearing 111^0 determine the date of sunrise appr. on 1 November (Celtic festival Samhain).

Table 3. Division of the year into eight parts

	λ_S [^{0}]	δ	A	Direction	Date (2005)	Event
1	0	0	90^0	KR-E	20 III	Spring equinox
2	45	$16^0 26'$	$64^0 03'$	KR-S_1	5 V	Beltane
3	90	$23^o 26'$	$51^0 46'$	KR-S_2	21 VI	Sommer solstice
4	135	$16^0 26'$	$64^0 03'$	KR-S_1	7 VIII	Lughnasa
5	180	0	90^0	KR-E	22 IX	Autumn equinox
6	225	$-16^0 26'$	$115^0 57'$	KR-S_3	7 XI	Samhain
7	270	$-23^o 26'$	$128^0 13'$	KR-S_4	21 XII	Winter solstice
8	315	$-16^0 26'$	$115^0 57'$	KR-S_3	3 II	Imbolg

The discussed problem becomes even more interesting when we transfer the points and the alignments onto the map. On the alignment KR-S_4, which points the winter solstice sunrise, there is a hill 412 metre high. It turned out that mound Krak is situated on the parallel with the point W412, Fig. 11. It was suprising that the length of the fragment of the meridian W412-PK equals the distance KR-KW.
It is worth mentioning that Krakus, Wanda and Krak mounds enclose the area of salt mining in Wieliczka region. The meridian of Wanda mound passes approximately through the middle of Wieliczka Salt Mine. Also the mounds in Solca and Komarowice are situated in salt mining area. In both areas the brine was explored in prehistoric times, which was the source of wealth for local communities.
The line KW-KK indicate the direction of moonrise and moonset – full moon - in their furthest points at either end of the 18.62 year cycle. It is worth mentioning that the line parallel to line WA-KK and leading through Krakus mound crosses Wawel Hill (WA). It could mean that for the observer standing on the top of Wawel Hill Krakus mound was founded in the direction of major standstill southern moonrise M_2 , Fig. 10 and 11.

3. SUMMARY

It has been proved that directions given by mounds Krakus and Wanda (and also Krakus and Krak) determine two dates of sunrise and two dates of sunsets. The above dates divide a year into four parts and they are strictly connected with Celtic calendar and festivals. The dates are symetrical reference dates of two solstices and two equinoxes and together divide a year into eight approximately equal parts. It is reasonable to assume that Krakow's prehistoric mounds were not only probable burial places but had also practical aspects like creation of a calendar defining seasons and the time for household activities and holidays.

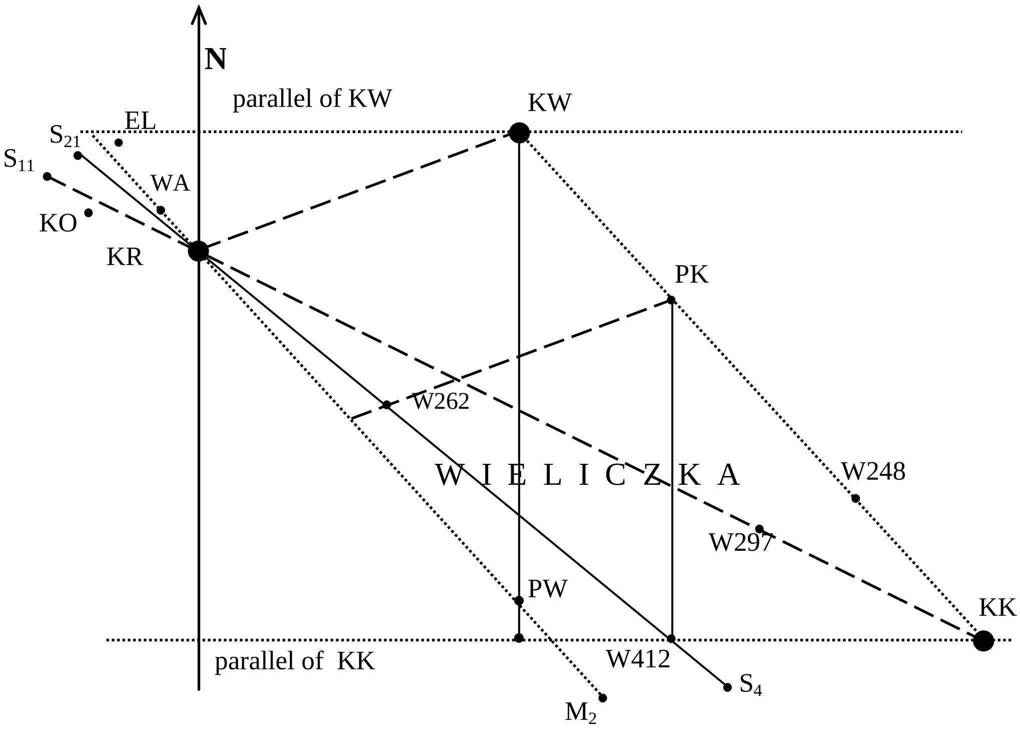

Fig. 11. Astronomical alignments in the area of Krakow and Wieliczka

In Cracow Saltworks Museum located underground – 135 metres below the surface – in Salt Mine Wieliczka we can see that the oldest traces of salt production found near Wieliczka are connected with the exploitation of surface brines going back to the Middle Neolithic Period (around 3500 B.C.). They included equipment consisting of brine channels, containers, furnaces and a large storage house, as well as numerous conical vessels used for salt briquetting and drying. The next stage of the development of salt production in prehistorical times is represented by chalice-shaped vessels (7th – 4th centures of B.C.) and brine utensils, large pottery vessels (around one metre tall) used for brine evaporation. The Pre-Roman (400 B.C. – 100 AD) and Roman (100-400 AD) periods are represeted by the relicts of the Celtic and Przeworsk cultures and include various form of ceramics, e.g. vessels made on a potter's wheel, hand-mills, part of armours, coins, glass objects and ornamental claps (Jodłowski, 2006). The above archaeological remains show that in ancient times people who lived in the area of Krakow and Wieliczka were far more sophisticated than was at first thought.

Acknowledgement

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