Morphometric analysis of a drainage basin with Oyu Tolgoi Cu-Au deposit, South Mongolia

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I. INTRODUCTION

Morphometric analysis represent relatively simple approaches to describe basin processes and to compare basin characteristics. This study allows the description of the physical changes in a drainage system over time in response to natural disturbances or human impacts. The drainage characteristics for Oyu Tolgoi deposit studied to describe and evaluate their hydrological characteristics by analyzing topographical maps and satellite images. Scholars would attend to morphometric study, regarding with Mongolia hasn't been publishing papers for this subject since the end of 1980's.

II. STUDY AREA

The drainage basin of Oyu Tolgoi deposit, one of the largest Cu-Au porphyry deposit in the world is located in the South Mongolia, approximately 550-600 km from the Ulaanbaatar city.The drainage basin of Oyu tolgoi deposit (Otdb) covers an area of 1675.2 km2 on a scale of 1:500,000 (Fig. 1). The basin lies between latitudes $106^0$00' and $107^0$30'N and longitudes $42^0$40' and $43^0$20' E. The maximum elevation basin ranges from 1,491 m in the northwestern to 950 m in the southeastern. Area has several springs, not any river, therefore all of streams are dry valley network including ravines and gorges.

Geology

The area occurs within the Gurvansaikhan island arc terrane (Badarch et al., 2002). Regional geology consists of Siluro-Carboniferous sedimentary and volcanic sequences dominated by terrigenous sedimentary and intermediate to felsic volcanic rocks. Terrigenous sedimentary rocks are fine grained, interbedded sandstone, siltstone, argillite, sometimes limestone and conglomerate with significant volcanics. Volcanics are massive, porphyritic augite basalt (Alagbayan formation) to rhyolite flows and andesitic and dacitic to rhyolite tuff. These sequences are intruded by Devonian syenite and granite and by Carboniferous diorite, granite, granodiorite and syenite bodies and by Permian REE rich peralkaline granite complex (Khanbogd massive). Cretaceous (Bayanshiree formation) to Quaternary sediments are overlied about 75% of whole area (Perello et al., 2001; Kirwin et al., 2005; Khashgerel, 2006; Gerel, 2009).

III. MATERIALS AND METHODS

A topographic map of 1:500,000 scale and LANDSAT 8 satellite image were used as a base for the delineation of Otdb. The morphometrics parameters were divided in three categories: basic parameters, derived parameters and shape parameters. The data in the first category includes area, perimeter, basin length, stream order, stream length, maximum and minimum heights and slope. Those of the second category are bifurcation ratio, stream length ratio, RHO coefficient, stream frequency, drainage density, drainage texture, basin relief and relief ratio. The shape parameters are elongation ratio, circularity index and form factor. The drainage network of the basin was analysed as per Horton's (1945) laws and the stream ordering was made after Philosophov (1960) and Strahler (1964).

IV. RESULTS AND DISCUSSION

Drainage basin morphology are regarded into structures, such as uplifts and depressions, for example, Duulgat, Khatsavch and Ulaan uul uplifts and Bayan ovoo, Ereen khongor and Galba gobi depressions, as seen from gravimetric survey (Burenkhuu et al., 1995) and drainage combined map (Fig.2). But Otdb has not sub-divided to sub-basins.

Basic parameters

Area (A) and *Perimeter (P)*

The entire drainage area of Otdb is 1675.2 km2. The perimeter is the total length of the drainage basin boundary. The perimeter of Otdb is 225.5 km, and is shown in Table 1.

Basin length (L)

The basin length corresponds to the maximum length of the basin and if there have a sub-basins, could measure parallel to the main drainage line. The basin length of Otdb is 93 km.

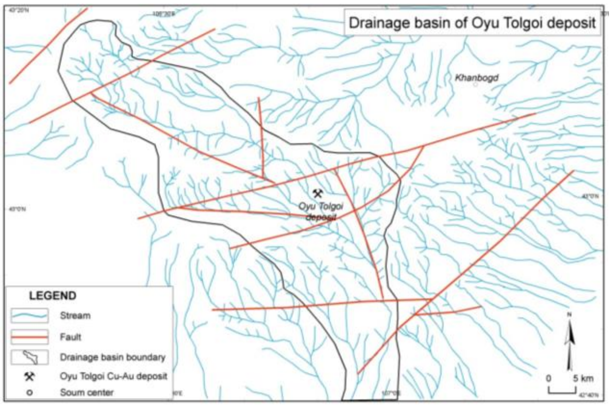

Figure 1. Drainage density map of Oyu Tolgoi deposit

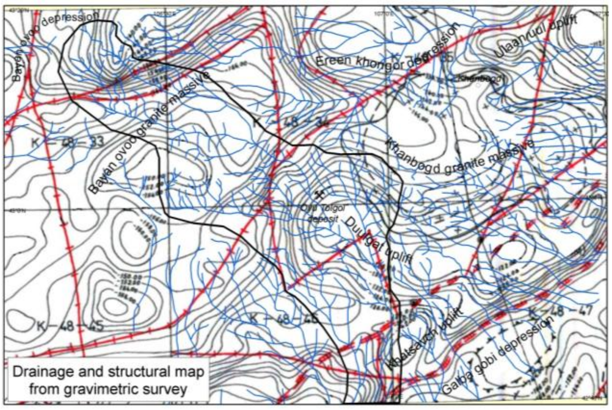

Figure 2. Combined map of drainage and structure. Streams are accorded with faults and geological structures from gravimetric survey

Stream order (Nu)

Stream order, or classification of streams based on the number and type of tributary junctions, has proven to be a useful indicator of stream size, discharge and drainage area (Strahler, 1957; Philosophov, 1960; Bold, 1987). The details of stream characteristics confirm Horton's first law (1945) ''law of stream numbers'' which state that the number of streams of different orders in a given drainage basin tends closely to approximate an inverse geometric ratio. Otdb is designated as a fifth order basin.

Table 1. Basic, derived and shape parameters of Otdb

Basic parameters						Derived parameters						Shape parameters		
A	P	L	H	h	Sb	RHO	Fs	Dd	T	R	Rr	Re	Rc	Ff
1675.2	225.5	93	1492	950	5.81	0.30	0.12	0.60	0.07	542	5.83	0.50	63.59	0.194

Table 2. Detailed values of some parameters

Stream order	N	Lu	Lt	Rb	Rl
I	151	0.28	679.5	3.87	0.78
II	38	0.22	163.4	3.80	0.83
III	9	0.18	68.7	2.25	0.94
IV	3	0.17	53.7	1.50	0.91
V	1	0.16	37.8	0.00	0.00
	202		1003.1	2.86	0.87

Stream length (Lu)

The stream length characteristic confirms Horton's second law (1945) ''laws of stream length,'' which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio. Most drainage networks show a linear relationship with a small deviation from a straight line (Chow 1964). The values of length (Lu) and total stream length (Lt) are shown in Table 2.

Maximum and minimum heights (H, h)

The maximum and minimum height corresponds to the highest and lowest point of the basin. The maximum height of Otdb is 1,491 m (Kharaat mountain) in the northwest, and the minimum height is 950 m in southeastern sector of basin.

Slope

The slope angle of a basin is a morphometrical factor of hydrological relevance. Steep slopes generally have high surface run-off values and low infiltration rates. Sediment production thus tends to be high except when largely barren slopes are concerned (Verstappen 1983). The basin slope was calculated applying the following formula:

$Sb = H – h / L'$

where H and h are the maximum and minimum basin heights, respectively; and L' is the horizontal length of the basin. The Otdb slope is 5.81. This value is in relationship with the gradual topography of the basin area.

<u>Derived parameters</u>

Bifurcation ratio (Rb)

This is an adimensional parameter that expresses the ratio of the number of streams of any given order (Nu) to the number in the next lower order (Nu+1) (Horton, 1945). Therefore, it is defined as:

$Rb = Nu / N(u+1)$

This is a very important parameter that expresses the degree of ramification of the drainage network. The Rb of Otdb is 2.86 (Table 2).

Stream length ratio (Rl)

The basin stream length ratio has been calculated by applying the following formula:

$Rl = Lu / Lu - 1$

where Rl = stream length ratio, Lu = stream length order u and Lu-1 = stream segment length of the next lower order. Rl between successive streams orders varies due to differences in slope and topographic conditions, and has an important relationship with the surface flow discharge and erosional stage of the basin (Sreedevi et al., 2004). The value of Rl for the Otdb is 0.87 (Table 2).

RHO coefficient (RHO)

This parameter was defined by Horton (1945) as the ratio between the stream length ratio (Rl) and the bifurcation ratio (Rb):

$RHO = Rl / Rb$

It is an important parameter that determines the relationship between the drainage density and the physiographic development of the basin, and allows the evaluation of the storage capacity of the drainage network (Horton 1945). It is influenced by climatic, geologic, biologic, geomorphologic and anthropogenic factors. The RHO of the basin is 0.30 (Table 1).

Stream frequency (Fs)

The stream frequency (Fs) was defined by Horton (1945) as the ratio between the total number of stream segments of all orders in a basin and the basin area:

$Fs = \sum Nu / A$

where ∑Nu = total number of stream segments of all orders, and A = basin area.

The Fs of the whole basin is 0.12.

Drainage density (Dd)

According to Horton (1945), the drainage density (Dd) is defined as the total length of streams per unit area divided by the area of drainage basin. It is expressed as:

$Dd = \sum Lt / A$

where ∑Lt = total length of all the ordered streams, and A = area of the basin.

Dd is a measure of the degree of fluvial dissection and is influenced by numerous factors, among which resistance to erosion of rocks, infiltration capacity of the land and climatic conditions rank high (Verstappen 1983). The Dd of Otdb is 0.60.

Drainage texture (T)

The drainage texture (T) is an expression of the relative channel spacing in a fluvial dissected terrain. It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development of a basin (Smith 1950). It can be expressed by the equation (Smith 1950):

$T = Dd \times Fs$

where Dd = drainage density, and Fs = stream frequency. The value of T for the basin is 0.07.

Basin relief (R)

Basin relief is the difference in elevation between the highest and the lowest point of the basin:

$R = H - h$

The R controls the stream gradient and therefore influences floods patterns and the amount of sediment that can be transported (Hadley and Schumm 1961). The relief of Otdb is 542 m and have small value of R due to physiographic hilly structure of the area.

Relief ratio (Rr)

Schumm (1963) exposed that Rr is the dimensionless height–length ratio between the basin relief (R) and the basin length (L):

$Rr = R / L$

The Rr of Otdb is 5.83 and the value of the basin is low due to the presence of actively erosed rocks in the area.

<u>Shape parameters</u>

Elongation ratio (Re)

Elongation ratio (Re) was defined for Schumm (1956) as the ratio between the diameter of a circle of the same area as the basin (D) and basin length (L). The Re is calculated by using the following formula:

$Re = D / L = 1.128 \times \sqrt{A} / L$

where A = area of the basin, L = basin length, and 1.128 is a constant.

The Re of Otdb is 0.50. This value is indicative of elongated shapes.

Circularity index (Rc)

The circularity ratio (Miller 1953; Strahler 1964) is expressed as the ratio of the basin area (A) and the area of a circle with the same perimeter as that of the basin (P):

$Rc = 4\pi A / P^2$

where Rc = basin circularity, P = basin perimeter, A = area of the basin and 4 is a constant.

The Rc of Otdb is 63.59. This value is indicative of the abundant of circularity.

Form factor (Ff)

Horton (1945) proposed this parameter to predict the flow intensity of a basin of a defined area. The Ff of a drainage basin is expressed as the ratio between the area of the basin (A) and the squared of the basin length (L^2). Therefore, the Ff is expressed as:

$Ff = A / L^2$

The Ff of Ordb is 0.194. The index of Ff shows the inverse relationship with the square of the axial length and as a direct relationship with peak discharge (Gregory and Walling 1973).

V. CONCLUSION

The stream ordering system of Otdb reveals a high hierarchization and high degree of ramification of the watershed (Horton 1945). Lower order streams mostly dominate the basin. Rb for the basin is the expected value relative to uplifted or highly dissected areas (Horton 1945). The mean Rb (2.86) indicates that the drainage pattern is not much influenced by geological structures (Strahler 1964). This value also is in relationship with the elongate shape of the basin (Schumm 1956). The development of stream segments is affected by slope and local relief (Strahler 1964). The particularity of area is very important considering the management objective in the basin and a progressive land use pressures.

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1. Badarch G., Cunningham W., Windley B., 2002. A new terrane subdivision for Mongolia: Implications for the Phanerozoic crustal growth of Central Asia. Journal of Asian earth sciences 21, no.1, 87-110
2. Bold Ya., 1987. Introduction to geomorphology and study. Ulaanbaatar, 87 p. (in mongolian)
3. Burenkhuu E., Gotovsuren A., Badarch G., Dagvatseren A., 1995. Geological complex mapping report to 1:200,000 scale for Galba gobi area. Ulaanbaatar, #4877, in archive of Geological Information Center
4. Chow Ven T (ed) (1964) Handbook of applied hydrology. McGraw Hill Inc., New York
5. Gerel O., 2009. Copper deposits of Mongolia. In book: Geology and mineral resources of Mongolia, vol. 6, pp. 47-84 (in Mongolian)
6. Gregory KJ, Walling DE (1973) Drainage basin form and process: a

geomorphological approach. Wiley, New York, 456pp

7. Hadley RF, Schumm SA (1961) Sediment sources and drainage basin characteristics in upper Cheyenne River Basin. U.S. Geological Survey Water-Supply Paper 1531-B, 198 pp
8. Horton RE (1945) Erosional development of streams and their drainage basins. Hydrophysical approach to quantitative morphology. Geol Soc Am Bull 56(3):275–370
9. Khashgerel B., 2006. Geology and reconnaissance stable isotope study of the Oyu Tolgoi porphyry Cu – Au system, South Gobi, Mongolia. Economic geology 101, 503-522
10. Kirwin D., Forster Ch., Kavalieris I., Grane D., Orssich C., Panther C., Garamjav D., Munkhbat T., Niislelkhuu G., 2005. The Oyu Tolgoi copper – gold porphyry deposits, South Gobi, Mongolia. In Geodynamics and metallogeny of Mongolia, IAGOD guidebook series 11, London, 175-191
11. Perello J., Cox D., Garamjav D., Sanjdorj S., Diakov S., Schissel D., Munkhbat T., Oyun G., 2001. Oyu Tolgoi, Mongolia: Siluro – Devonian porphyry Cu – Au – (Mo) and high sulfidation Cu mineralization with a Cretaceous chalcosite blanket. Economic geology 96, 1407-1428
12. Philosophov V.P., 1960. Short manual of morphometric methods revealing tectonic structure. Saratov, USSR, 69 pp. (in russian)
13. Schumm SA (1956) Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol Soc Am Bull 67:597–646
14. Schumm SA (1963) Sinuosity of alluvial rivers on the great plains. Geol Soc Am Bull 74:1089–1100
15. Smith KG (1950) Standards for grading texture of erosional topography. Am J Sci 248:655–668
16. Sreedevi PD, Subrahmanyam K, Ahmed S (2004) The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environ Geol 47:412–420
17. Strahler AN (1957) Quantitative analysis of watershed geomorphology. Trans Am Geophys Union 38:913–920
18. Strahler AN (1964) Quantitative geomorphology of drainage basin and channel networks. In: Chow VT (ed) Handbook of applied hydrology. McGraw Hill Book Co., New York, pp. 4–76
19. Verstappen H (1983) The applied geomorphology. International Institute for Aerial Survey and Earth Science (I.T.C), Enschede, The Netherlands, Amsterdam, Oxford, New York