（様式２）

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論文題名：DESIGN OF CROWN PILLAR AND MINING SYSTEM IN TRANSION FROM OPEN PIT TO UNDERGROUND FOR STEEP LOW-GRADE ORE DEPOSIT IN FLOURITE MINE, MONGOLIA(モンゴルの蛍石鉱山における急傾斜低品位鉱床を対象とした露天採掘から坑内採掘移行時のクラウンピラーの設計および採掘方法に関する研究)

区　　分：甲

論　文　内　容　の　要　旨

Open pit mining method is applied for low-grade and large-scale deposits are extracted near the surface. In case the deposit is endowed from shallow to deep underground, as the stripping ratio which is the ratio of waste rock to be removed to ore increases, the transition of from open pit to underground have to be conducted at any stage in consideration of the economic efficiency and safety associated with mining. Especially, in case that ore deposit is extracted by open pit mining method with steep pit slope, as the depth of open pit mining operation and the striping ratio are increased rapidly, the transition to underground mining operation has to be investigated in consideration of feasibility study. Even though, there are many examples of development of steeply inclined high-grade deposits, but there are few examples of transition from open pit mining to underground mining for large-scale steeply inclined low-grade deposits. In addition, in case that a low-grade steeply inclined deposit is developed, only large-scale open stoping methods such as sublevel open stoping method and/or vertical crater retreat method can be applied from an economic point of view. However, in order to apply the large-scale open stoping method safely and efficiently, the guidelines for appropriate design of crown pillar, which is the rock mass remained between the bottom of the pit and the uppermost stop, and mining system for deep deposits have to be developed. From these backgrounds, the purpose of this research is to develop the guidelines for optimum designs of crown pillar and sublevel open stoping system, which is large-scale mechanized mining system, in transition zone from open pit to underground for steep low-grade ore deposit. To accomplish the purpose of this research, Zuun Tsagaan fluorite Mine, which is one of the large-scale low-grade deposits in Mongolia and is rare in the world, is chosen as the representative mine site. This dissertation consists of seven chapters and the main contents in each chapter are listed as follows:

Chapter 1: This chapter describes the situation regarding the development of low-grade ore deposits from open pit mining to underground mining and the features of underground mining systems. This chapter describes the objectives of this research.

Chapter 2: This chapter describes the conditions of Zuun Tsagaan Fluorite Mine and features of sublevel open stoping method. Based on the data of geological conditions, it can be said that the sublevel open stoping can be applied for development of underground mine because the rock mass conditions of deposit, hangingwall and footwall are good. In addition, it can also be said that the development of underground mine from the open pit mine by using sublevel open stoping method can be conducted economically based on the results of Feasibility Study.

Chapter 3: This chapter discusses the appropriate thickness of crown pillar at Zuun Tsagaan Fluorite Mine by means of numerical simulation. From the results of numerical simulation, it can be concluded that 15m thickness of crown pillar should be left in case that the deposits with the dip of 70 degree is extracted by sublevel open stoping with the stope of 10 m width and 30 m height in order to mitigate the effect of stress concentration generated around the toe of open pit slope on the stability of crown pillar and the uppermost stope.

Chapter 4: In order to discuss and evaluate the effects of geological and mining conditions on the stabilities of crown pillar, stopes and open pit slope quantitatively by applying sublevel open stoping method, a series of numerical analysis is conducted by means of FLAC3D ver.7.0. It is found that the stabilities of crown pillar and stope are decreased significantly with decreasing the dip of deposit, increasing the width of

the stope and the stress ratio of the horizontal ground stress to the vertical one. It is also found that the underhand sublevel open stoping method gives a better stability conditions of crown pillar and the rock mass around the open pit slope than the overhand one. In addition, as the topography of open pit such as the height and the average overall angle of final pit wall also has an obvious impact on the stability of crown pillar, the rock mass behavior around the corner of the crown pillar and the toe of open pit slope has to be monitored in case of the transition from open pit operation to underground one.

Chapter 5: Based on the above results, a series of numerical analysis by changing the ground and mining conditions are conducted in order to clarify the applicable conditions of the sublevel open stop method. It is assumed in this analysis that a crown pillar with a thickness of 15 m is left at the bottom of the pit, and then three mining stopes with a width of 10 m and a height of 30 m are excavated below the crown pillar while a sill pillars with a thickness of 10 m are left between adjacent stopes. From the results of a series of numerical simulations, it can be found that the stability of the crown pillar and the open pit slope are maintained in case that the stress ratio is less than 1.0, the dip of deposit is around 70 degree, the rock mass conditions of deposit, hangingwall and footwall are 60 or more in the Geological Strength Index (GSI). Hence, it is clarified that the deposit can be extracted by sublevel open stoping method without any supports nor measures. On the other hand, in case that the GSI of deposit and hangingwall and footwall rock masses is smaller than 50, the sublevel open stoping method cannot be applied and the cut-and-fill toping method has to be applied in order to maintain the stabilities of crown pillar and open pit slopes. In addition, in this case, the backfilling material needs to be changed from waste rocks to cement paste as the quality of rock mass decreases and/or the mining depth increases. Furthermore, even if the rock mass condition is around 60 in GSI, in case that the dip of deposits is relatively gentle such as around 40-50 degree and the stress ratio is larger than 1.5, as the failure zone is developed and propagated around the open pit slope on the hangingwall side, the stability of open pit slope is dramatically decreased and the fragmented ore in the stope may be diluted with a large amount of waste rocks in the hangingwall. Therefore, the stability of the rock mass around the stope has to be improved by taking measures such as the installation of cable bolts in the hangingwall of the stope. It is necessary to discuss whether or not underground mining operation can be continued by applying the sublevel open stoping method with taking into consideration the grade of the ore and the mining cost including support and measures.

Chapter 6: A highly-recovery mining method for high-grade ore around the bottom pf the open pit is discussed and proposed in this chapter. As the forming of artificial strong roof above the stope backfilled with the cement paste and installation of cable bolt in the roof of stope and crown pillar, the stability of stope and crown pillar can be improved dramatically and the effects of mining operation on the stability the open pit slope can be decreased. As the results, the thickness of ore pillar remained as crown pillar can be decreased from 15 m to 5 m and then the high-grade ore recovery around the bottom of the open pit can be increased.

Chapter 7: This chapter summarizes and concludes the results and findings of this research.