

## Acid Mine Drainage at Sarcheshmeh Copper Open Pit Mine

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**ABSTRACT:** Acid Mine Drainage (AMD) problems are predominantly chemical, and are of great complexity. Any deposit containing sulphide minerals, particularly pyrite, is a potential source of AMD. Acid mine drainage is a serious environmental and economic concern. Pyrite oxidizes when it comes into contact with air and water, and sulphuric acid is produced. This lowers the pH of the water and increases the solubility of many metals. The planning of a mine and design of pit walls can be affected by environmental factors. By making environmental assessments, quantitative estimates of the effects of the mine on its surroundings can be considered during design. This research was directed toward evaluation of alternative procedures to minimize the drainage of poor quality water from the mine.

### 1 INTRODUCTION

The Sarcheshmeh porphyry copper-molybdenum deposit is located in southern Iran. A large-scale open pit mine was started up by the National Iranian Copper Industries Co. (NICICO) in 1974. It is currently the largest open pit mine in Iran. The Sarcheshmeh pit is oval shaped, about 3000m long by 1800m wide. The ore body contains 1200 Mt. of ore. The average sulphide is 0.7% copper and approximately 0.03% molybdenum. The mine produces 100,000 tons of copper and 2200 tons of molybdenum concentrate per year.

The planning of a mine and design of pit walls can be affected by environmental factors. By making environmental assessments, quantitative estimates of the effects of the mine on its surroundings can be considered during design. Engineering alternatives have to be compared on criteria that include specific environmental requirements. It is important to make an early identification of potential problems in order to devise practical solutions. After an environmental plan is adopted, monitoring of key criteria throughout the operating stage is required to identify and correct deviations from the plan. This study focused on pyrite weathering during the productive life of a mine.

Various water types within the Sarcheshmeh mine workings can be identified on the basis of quality differences. These water quality differences exist because of differences in rock types, mineral-

ogy, flow path length and travel time. In many instances these water types have been discharged directly into Sarcheshmeh River. To remove the dissolved metals or suspended solids a settling pond and liming facilities have been installed. The current activity in this regard involves minimizing the production of mine drainage, thereby eliminating or at least minimizing the mine drainage.

### 2 GEOLOGICAL SETTING

The Sarcheshmeh Copper Open Pit Mine is in southern Iran, at an average elevation of 2600m. It is located in the central part of an elongated NW-SE mountain belt, which is principally composed of folded volcano-sedimentary complex. The geology of Sarcheshmeh porphyry copper-molybdenum deposit is complex, with widely varying rock types. Mineralization in the Sarcheshmeh porphyry copper-molybdenum deposit is associated with a Late Tertiary granodiorite porphyry stock. The whole complex is criss-crossed by a series of inter-mineral and postmineral dikes. The original sub-circular Sarcheshmeh porphyry stock exhibits an east-west elongation due to dilation by the dike swarm, whose strike is predominantly NNW (Fig. 1). The highest-grade hypogen zone occurs as an annular ring in altered andesite around the periphery of the Sarcheshmeh stock (Waterman et al. 1975).

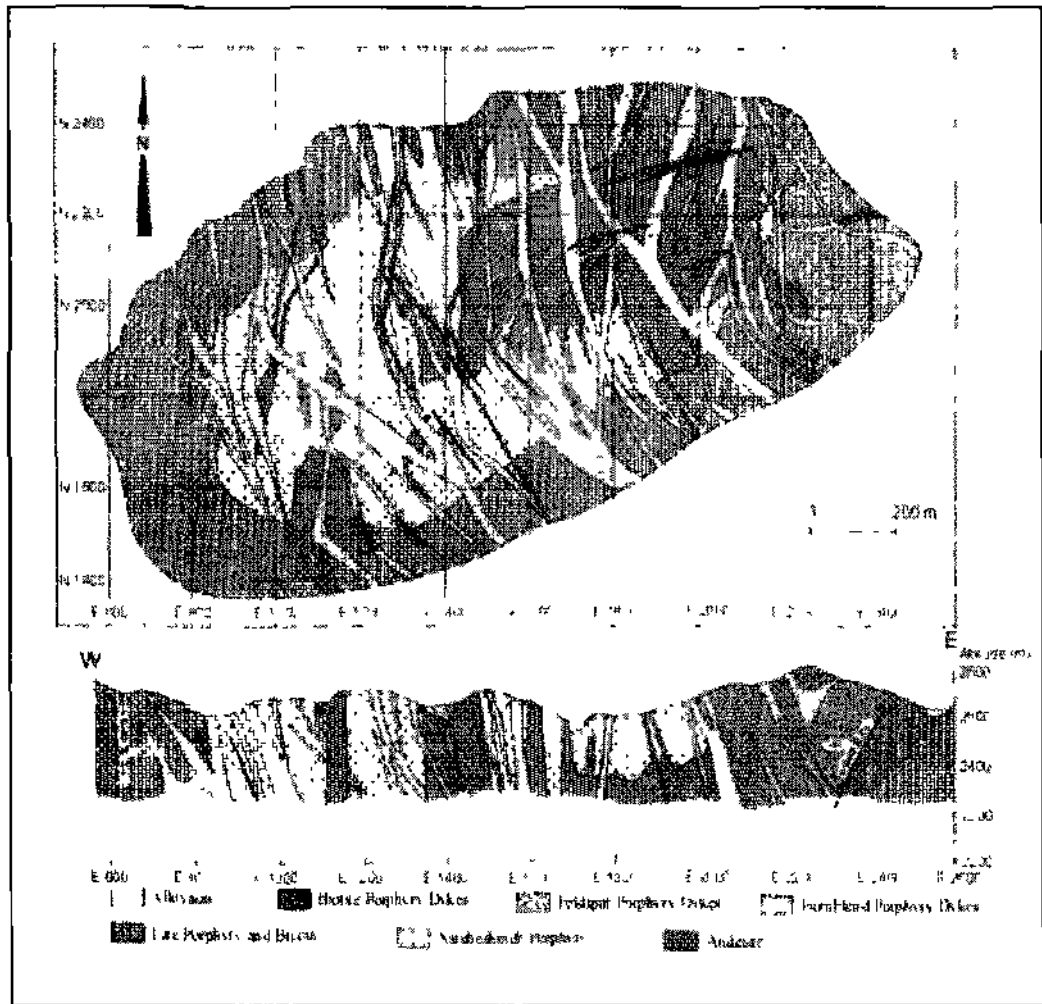


Figure 1 Distribution of the rock types at 2400m elevation within outer 0.40% copper line Sarcheshmeh deposit with geological section (Etminan, 1977).

### 3 HYDROGEOLOGY

The Sarcheshmeh mine has a catchment area of about 21 km<sup>2</sup> and average annual precipitation of about 440 mm, showing the direction and quantity of surface flow to the pit. Hydrogeological studies around the Sarcheshmeh area show that there are definite relationships between geologic, topographic, hydrogeologic and climate factors and existing ground water flow systems.

At Sarcheshmeh, structural features control to a large extent the location of groundwater entering a geologic formation. Hydraulic conductivity is fracture-controlled. Water enters the mine by two mechanisms:

a) Downward movement of water under saturated or unsaturated conditions within the cone of depression created by the mine

b) Lateral ground water movement to the margins of the mine

Water samples were collected at Sarcheshmeh, on a monthly basis over a one-year period. The results of this initial hydrologic investigation showed that the acid drainage is controlled structurally. Considering the structural information, the Sarcheshmeh pit was initially divided into 4 pit sectors in terms of the anticipated hydrogeological conditions as follows (Karimi Nasab 1997):

- West pit wall: the crests are parallel to the general strike of the dikes with a dip angle of 70° to 85°

towards the east. Considering the general hydraulic gradient from south to north, the dikes act as a barrier to acid water flow.

- South pit wall: the crests are approximately perpendicular to the strike of the dikes, which do not appear to act as structural barriers to acid water flow.

- East pit wall: hydrogeologically, this sector is similar to the west wall, but the dips of the dikes are against the bench slope.

- North pit wall: this is similar to the south wall.

An estimated 66,000 meters of surface exploratory diamond drilling has been completed in the mining area. This type of drilling is designed to reach ore bodies, which are usually more permeable than the surrounding rock. This type of exploration increases recharge to the groundwater flow systems by providing more interconnections between the surface and subsurface.

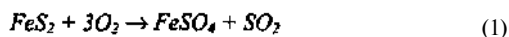
Hydrogeological problems from mining activities are related to the modification of the existing ground water flow system or the creation of a new flow system. Thus, future mining activities should incorporate hydrological variables in mine planning and surface-waste site selection procedures. Preventing acid mine drainage is much less difficult than curing acid mine drainage.

#### 4 BASIC PROCESS OF AMD

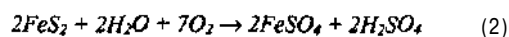
AMD problems are predominantly chemical, and of great complexity. Originally considered to be a problem associated only with coal mining, and particularly with abandoned mines, AMD is now known to occur as a result of the working of many other minerals. Any deposit containing sulphide minerals, particularly pyrite, is a potential source of AMD.

AMD is produced when a sulphide reacts with air and water to form sulphuric acid. The basic process occurs in three stages:

1) The oxidation of the sulphide, usually  $FeS_2$ . If the reaction takes place in a dry environment, water-soluble ferrous sulphate and sulfur dioxide are formed (Williams et al. 1979):

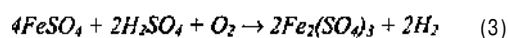


More commonly, the reaction occurs in the presence of water, with the direct formation of sulphuric acid:



2) Ferrous sulphate, in the presence of sulphuric acid and oxygen, can oxidize to produce ferric sulphate. This transformation is not controlled by the presence of water, but it appears that a bacterium

(*Thiobacillus ferro-oxidans*) is an essential mediator, and if it is not actually responsible for the oxidation, at the very least it greatly accelerates it. The reaction is:



3) The ferric iron so produced combines with the hydroxyl ( $OH$ ) ion of water to form ferric hydroxide. This is insoluble in acid, and precipitates:



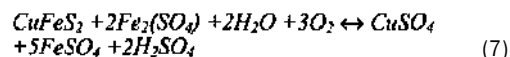
An alternative to this reaction occurs because the ferric iron may also enter the reaction with iron sulphide and "back-trigger" further oxidation, thus accelerating acid formation.



The sulphuric acid generated tends not to be found as high concentrations of free acid due to further reactions with other minerals.

At pH 3.5 or less, bacteria such as *Ferrobacillus ferrooxidans*, *F. Sulfooxidans* and *Thiobacillus ferrooxidans* accelerate the rate of conversion of  $Fe^+$  to  $Fe^{++}$ . Singer & Strumm (1970), noted that such bacteria may accelerate the reaction in equation 3 by a factor of  $10^6$  or more. The organism, which requires oxygen for growth, can also transform nickel, copper, zinc, molybdenum and other metallic sulphides (Hawley et al. 1971).

In addition to the formation of water with low pH and high iron, acid produced from the oxidation of pyrite may also dissolve other minerals which by themselves do not contribute to the formation of acid waters. The dissolution of the sulphide copper mineral chalcopyrite is an example.



Increased flow through mine workings during spring runoff flushes oxidation products from areas not normally in contact with water. Numerous pools of acid water also collect in mines during low flow periods. The influx of water during spring runoff flushes out these pools, with the addition of poor quality water to the system.

#### 5 SURFACE WASTE FEATURES

Acid production from surface waste features is governed by the following variables:

- oxygen
- availability of pyrite and other heavy metals
- moisture in the waste material

- d) availability of water to transport oxidation products
- e) physical location of the waste features

Surface waste features are vulnerable to flushing of oxidation products from within the waste material. Erosion of the waste material by surface water is also a problem.

## 6 AMD ASSOCIATED WITH MINING ACTIVITIES

Waste dumps that progress over or fill up drainage routes must also have special design considerations. If run-of-mine rock is end-dumped from the tip head, then given sufficient dump height, gravity will segregate the larger and smaller fragments. The larger material will roll to the bottom of the dump and will normally form a very permeable base. The finer material gathering in the upper portions of the dump will tend to form an almost impermeable surface. Waste dumps built with this natural segregation have free drainage and offer little chance of saturation unless the base material weathers rapidly. They will also have decreasing permeabilities through time. The high base permeability will allow the dumps to progress over small drainage routes and not block the flow.

Water quality problems associated with mining activities can be minimized by considering the following points:

- Hydro-geological site selection factors should be considered for the location of tailings disposal areas, waste rock storage areas, and low-grade ore storage areas planned for future mining activities. Disposal areas for tailings and waste rock are limited by the physical characteristics at Sarcheshmeh mine.
- Diversion of discharge to central flow points within the mine workings would help to eliminate the flushing of accumulated oxidation products or contamination of good-quality discharge sources.

## 7 ANALYSIS OF WATER QUALITY DATA

Water discharging from the pumping tests can be further subdivided based on whether or not the drill hole has encountered the ore body. The change in quality of water with time under at the constant pumping rate for 4 pumping stations are shown in Table 1. The water quality differences for each pumping station exist because of differences in rock types, mineralogy, flow path length and travel time. The quality of water after 99 hours (5 days) pumping was better than the first day of pumping test owing to limitation of available oxygen. Over a period of 19 months water flowing from streams or springs were sampled at 7 stations (Fig. 2). The water source was

thought to be from ground water originating from faults and fractures. Stream and spring water quality around the Sarcheshmeh pit is good. Figures 3-9 show quality variations for these sources. The quality of water from Sarcheshmeh River and dump No. 11 is lower than the other stations. Acid production from dumps near stream channels is a significant source of acid water and heavy metals in the Sarcheshmeh River. In waste rock leach the rate and amount of acidity and metals produced under saturated conditions are different compared to similar materials under unsaturated conditions (Keith. & Runnells 1995).

## 8 CONCLUSIONS

Preventing acid mine drainage is much less difficult than curing acid mine drainage. However, the following points are worth noting:

- a) Sulphide, water and oxygen are necessary.
- b) An excess of any one component can produce more acid.
- c) The reaction is auto-catalyzed by the presence of acid.
- d) Biological catalysis via Thiobacillus and Ferrobacillus can occur.
- e) The pyrite reactions control the presence of such toxic heavy metals as *Pb*, *Zn*, *Cd*, *Cu* in solution through pH.
- f) Acid production can be prevented by excluding oxygen, water or sulphide.

- Surface exploratory diamond drilling is designed to reach ore bodies, which are usually more permeable than the surrounding rock. This type of exploration increases recharge to the groundwater flow systems by providing more interconnections between the surface and subsurface.

- The results of pumping tests at the Sarcheshmeh mine have shown the significant role of rock types, mineralogy, flow path length, travel time and oxygen availability in acidic water production.

- Analysis of water quality data for different sources around the Sarcheshmeh pit has shown that dumps play an important role in acidic water and heavy metals production.

- Hydrogeological site selection factors should be considered for the location of tailings disposal areas, waste rock storage areas, and low-grade ore storage areas planned for future mining activities.

- It may be possible to divert surface water or re-route the shallow groundwater flow systems, recharging localized acid-producing areas in the upper workings in order to reduce the flushing of acid reaction products into the mine drainage system.

- Finally, the results of this research have strong implications for mine planning.

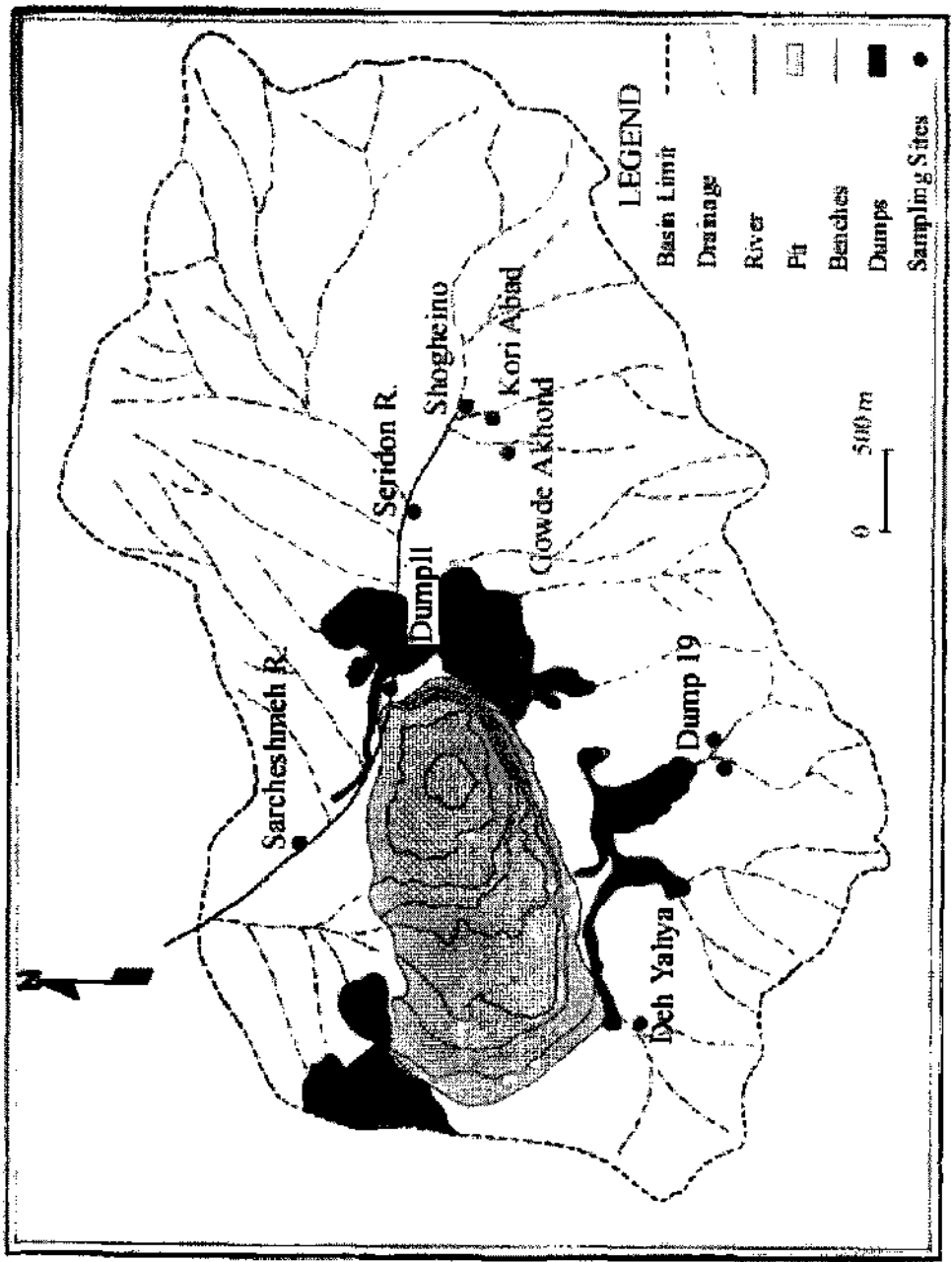


Figure 2. Sarcheshbuneh basin and location of water sampling stations.

Table 1. Water quality data for different pumping stations, during 99 hours of pumping test

Pumping station	Date	Sample	pH*	Ec	SO <sub>4</sub>	HCO <sub>3</sub>	Ca	Mg
PTW1	21/09/99	S <sub>1</sub>	5.9	3591	2400	20	560	230
	22/09/99	S <sub>2</sub>	4.3	2473	1900	0	416	160
	23/09/99	S <sub>3</sub>	6.3	2234	1900	5	460	130
	24/09/99	S <sub>4</sub>	6.3	1990	1700	11	408	120
	25/09/99	S <sub>5</sub>	6.4	1890	1640	54	350	120
PTW2	20/12/99	S <sub>1</sub>	7.6	280	59	98	41	8
	21/12/99	S <sub>2</sub>	7.3	280	59	100	42	8.8
	22/12/99	S <sub>3</sub>	7.2	290	64	100	42.8	8.6
PTW3	01/01/00	S <sub>1</sub>	6.7	1197	750	50	245	46
	05/01/00	S <sub>2</sub>	6.9	1117	690	65	220	45
	06/01/00	S <sub>3</sub>	6.6	1070	700	58	235	43
	07/01/00	S <sub>4</sub>	6.8	1077	700	82	240	43
	08/01/00	S <sub>5</sub>	6.8	1037	700	78	235	43
PTW4	29/02/00	S <sub>1</sub>	7.2	710	320	125	100	34
	01/03/00	S <sub>2</sub>	6.8	910	360	110	112	34
	02/03/00	S <sub>3</sub>	7.1	758	360	115	105	34
	03/03/00	S <sub>4</sub>	7.1	718	360	115	104	34
	04/03/00	S <sub>5</sub>	7	790	360	112	100	36

\*pH: in standard units, Ec: specific electrical conductance is reported as  $\mu\text{moh/cm}$  at 25°C, and other parameters are reported in ppm.

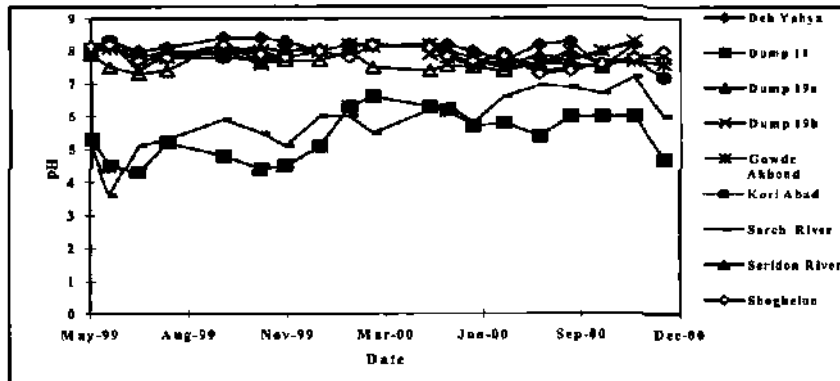


Figure 3. Variation of pH value for different sources of water around the Sarcheshmeh pit for May 1999 to December 2000.

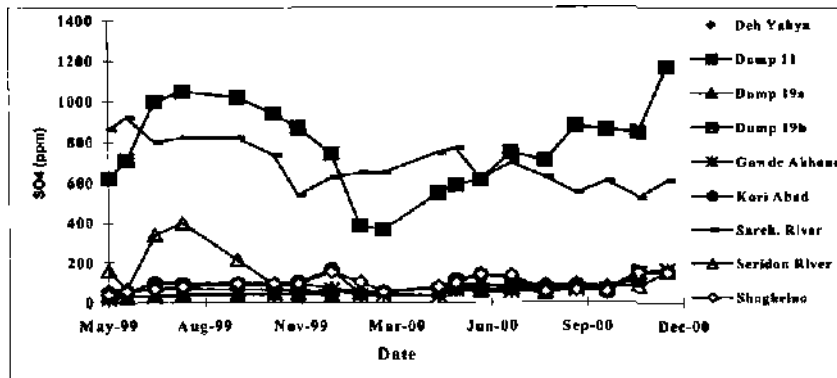


Figure 4. Variation of SO<sub>4</sub> ion for different sources of water around the Sarcheshmeh pit for May 1999 to December 2000

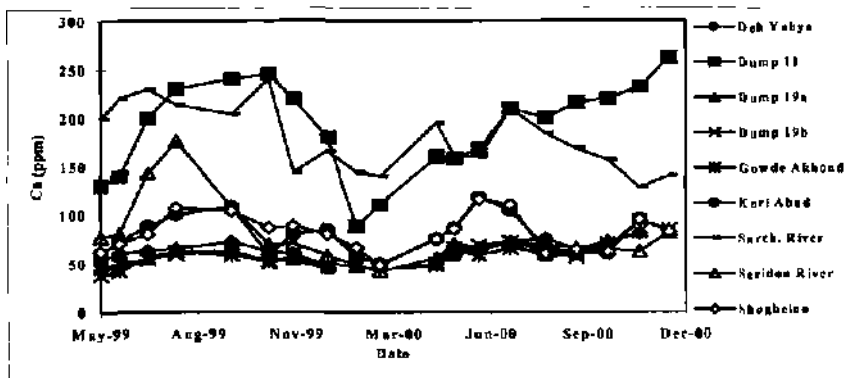


Figure 5. Variation of Ca ion for different sources of water around the Sarcheshmeh pit for May 1999 to December 2000.

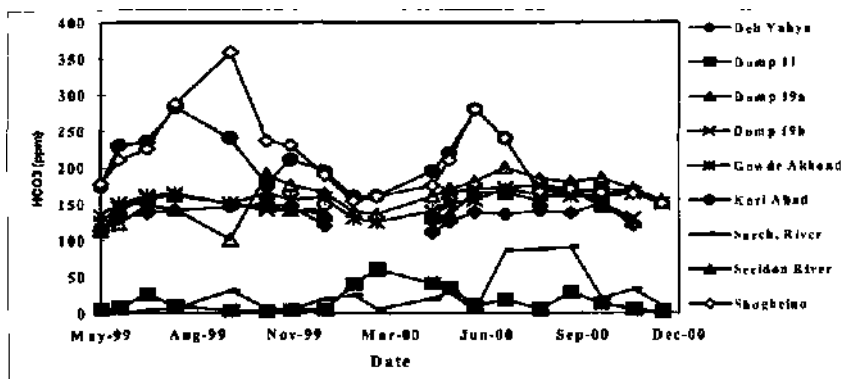


Figure 6. Variation of HCO<sub>3</sub> ion for different sources of water around the Sarcheshmeh pit for May 1999 to December 2000.

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#### REFERENCES

- Etmian, H., 1977, Le Porphyre Cuprifère de Sar Cheshmeh (Iran), Rôle des Phases Fluides Dans les Mécanismes d'Altération et de Minéralisation, *Ph. D. Thesis, Mémoire No. 34, Science de la terre de l'Université*. Nancy, France, 249 p.
- Hawley, J.R. & Shikaze, K.H. 1971. The Problem of Acid Mine Drainage in Ontario. *Can. Min. J.* 92(6): 82-93.
- Karimi Nasab, S. 1997. Stabilité de Talus Rocheux en Zone Sismique dans un Porphyre Cuprifère Mine de Sarcheshmeh, Iran. *Ph. D. Thesis Ecole des mines de Paris*. 325 p.
- Keith D.C. & Runnehs D.D. 1996, Expérimental Simulation of Waste Rock Weathering Under Unsaturated and Saturated Conditions at Iron Mountain, California, *Proceeding of the Third International Conference on Tailings and Mine Waste '96*, Fort Collins, Colorado. USA. 16-19 January, p.351.
- Singer, P. C. & Sirumm, Werner, 1970. Acidic Mine Drainage: The Rate Determining Step, *Science*, 167, p. 1121-1123.
- Waterman, G. C. & Hamilton. R. L. 1975. The Sarcheshmeh Porphyry Copper Deposit, Economic Copper Deposit. *Economic Geology*: 70: 568-576.
- Walder i F., Zimmer C. & Chavez Jr W.X. 1996. Mine Waste Site Characterization: Use of Andésite as an AMD Neutralizing Media, *Proceeding of the Third International Conference on Tailings and Mine Waste '96*, Fort Collins, Colorado, USA, 16-19 January, p.361.

