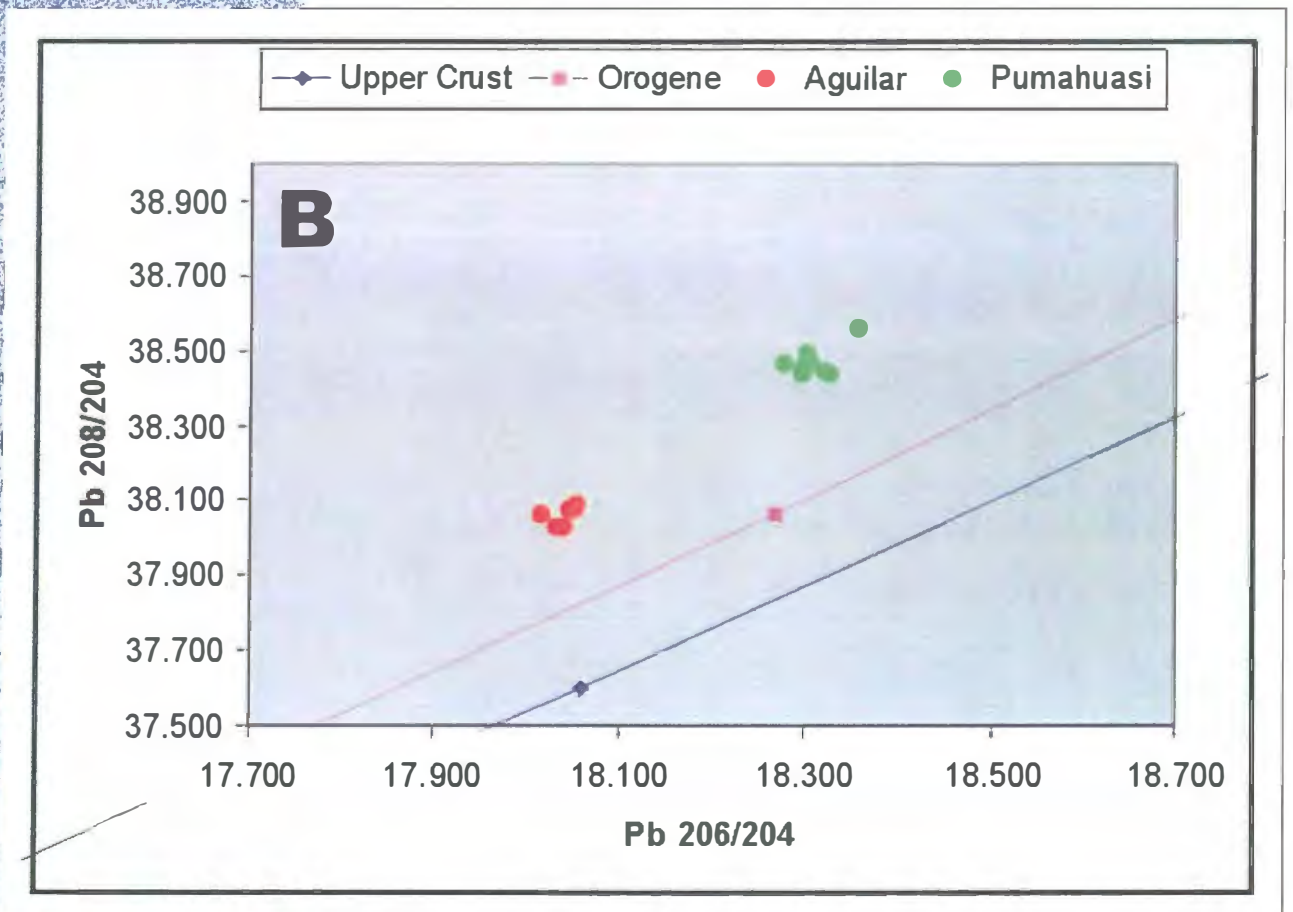


*Evaluation of the concept that  
Pumahuasi veins indicate a potential  
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**SEGEMAR**

SERVICIO GEOLÓGICO  
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**SECRETARÍA DE ENERGÍA Y MINERÍA**

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## ÍNDICE

### **EVALUATION OF THE CONCEPT THAT PUMAHUASI VEINS INDICATE A POTENTIAL FOR THE EXISTENCE OF UNDERLYING UNDISCOVERED SEDEX DEPOSITS, NORTHERN ARGENTINA**

INTRODUCTION	.....	1
METHODOLOGY	.....	1
GEOLOGY	.....	1
ISOTOPIC ANALYTICAL RESULTS	.....	2
DISCUSSION	.....	3
CONCLUSION	.....	6
REFERENCES CITED	.....	6



EVALUATION OF THE CONCEPT THAT PUMAHUASI VEINS INDICATE A  
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## INTRODUCTION

We have been asked by SEGEMAR to comment on the possibility that the Pumahuasi veins (Figure 1) may be mobilized Sedex mineralization and that their presence indicates an exploration potential for Sedex base metal deposits, similar to the Aguilar deposit, in the Pumahuasi area.

## METHODOLOGY

To evaluate whether the veins do, indeed, represent a physical mobilization from an underlying Sedex deposit, one needs to note the geological relationship between the veins and the host rocks. Assuming metamorphism was the agent responsible for the mobilization, if the veins were to be derived from an assumed stratiform deposit, the veins should exhibit evidence of syn-metamorphic emplacement. Furthermore, sulphide material physically mobilized out of a sulphide mass should retain the same Pb- and S-isotopic values as the parent body.

Accordingly, we examine geological information, Pb- and S-isotope analyses to examine this possible relationship.

## GEOLOGY

### **Aguilar deposit**

The Aguilar Sedex deposit is an important Zn-Pb-Ag producer in northwestern Argentina about 150 km north-northwest of the town of Jujuy. The deposit has an estimated production to date of 40 to 50 million tonnes of high-grade ore and has been in continuous production since 1936.

Aguilar shows most of the features typical of Sedex deposits. It occurs in a Tremadocian-aged transition between Cambrian quartzite and thick overlying slates and wackes of the Acoite Formation. The deposit has been metamorphosed by an adjacent Cretaceous hornblende granite. The ores are highly variable in both texture and composition. Orebodies range from massive sphalerite to massive galena with all intermediate compositions and variations to low grade disseminated ores. Some of the zinc-rich ores

are banded and some of them are massive, banded, and pyrite-rich. In addition there is a wide variety of breccia or conglomerate-hosted ore which represents both syndepositional slump breccias and tectonic brecciation of silicate beds in the ductile sulphide matrix. The deposit has a high Mn content, mainly in sphalerite and in Mn-rich silicate minerals (garnet, bustamite, rhodonite/rhodochrosite). A distinctive spessartine-rich garnet rock (coticule) is present near the periphery of the banded ores.

### **Pumahuasi veins**

One hundred and fifty kilometres north of the Aguilar Mine, near the Bolivian border, a group of medium to small base metal veins (Pumahuasi veins) was mined early in this century for Pb; the veins also contain accessory Zn and Ba.

The Pumahuasi group of veins outcrop in an area about 25 km by 10 km wide between the villages of Cangejillos and La Quiaca. The veins range in thickness from a few tens of cm to about 2 m and can be traced for distances up to a maximum of perhaps 600 metres. Some of the more important past producers include Mina Pumahuasi, Mina la Belgica, and Mina la Pulpera. Descriptions of individual deposits visited are contained in the trip reports by each of us that accompany this report.

The Pumahuasi veins occur in rocks of the Acoite Formation. The veins display a uniformly steep dip; strike directions are widely scattered about a general east-west direction. Veins clearly cut the dominantly north-south bedding and cleavage in the Acoite Formation. The veins contain a variety of mineralogical associations but, in general, are composed of carbonate (Mn-bearing siderite), with accessory barite in some cases. Sphalerite and galena are universally present in highly variable quantities. Accessory minerals include quartz, chalcedony, chalcopyrite and a suite of sulphide and secondary oxide minerals. The Mina Olga occurrence is located at the north end of the Pumahuasi group of veins and, in contrast to the other occurrences, contains a primary mineralogy of bornite, galena and barite.

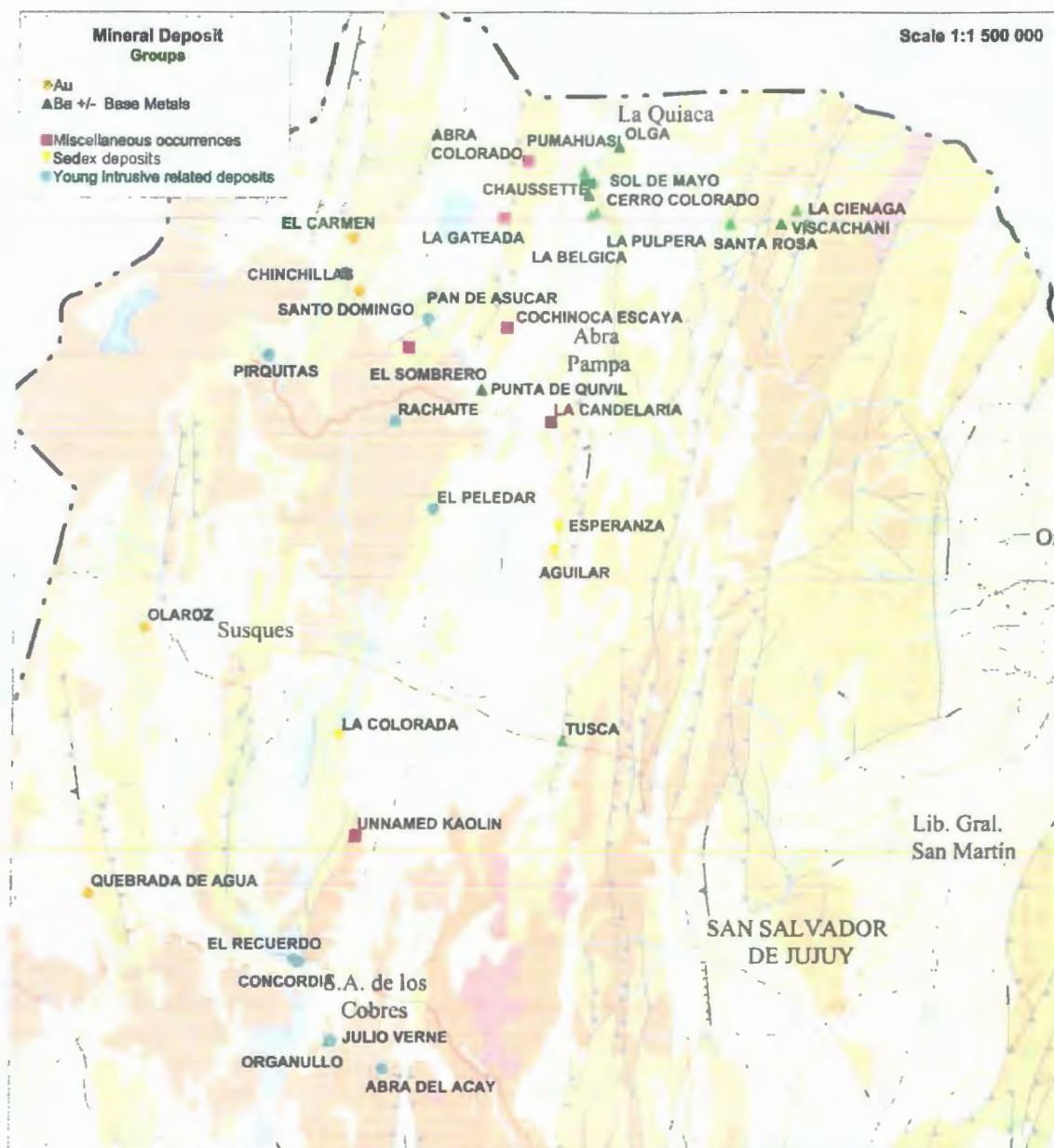


Figure 1: Locations of selected mineral occurrences in northwestern Argentina. Pumahuasi veins listed are Olga, Sol De Mayo, Chaussette, Cerro Colorado, La Pulpera and La Belgica. The Tusca and Abra de Quevil occurrences may be similar occurrences related to the Pumahuasi group (see trip report).

## ISOTOPIC ANALYTICAL RESULTS

### Pb-isotope analyses

Geospec Consultants, Edmonton, Canada, carried out the Pb isotope analyses. The following excerpt from their report describes the analytical methods used.

Clean galena grains were carefully selected under binocular microscope and extracted from the 25 supplied galena bearing sample material. Separated grains were dissolved in 2N HCl and gently evaporated to dryness. PbCl<sub>2</sub> crystals formed by

fractional crystallization were purified and finally cleaned in 4N HCl and super pure H<sub>2</sub>O.

Approximately 500 ng of extracted lead (in PbCl<sub>2</sub> form) was loaded on Rhenium filament using the standard silica gel - phosphoric acid technique and the isotopic composition was measured in a Micromass MM30 mass spectrometer. Overall reproducibility of the lead measurements in the laboratory was determined from a large number of NBS SRM 981 and SRM 982 lead standard measurements performed routinely on this instrument. At 1 sigma error level, the reproducibility of the measured isotopic ratios is as follows:



$^{206}\text{Pb}/^{204}\text{Pb}$        $^{207}\text{Pb}/^{204}\text{Pb}$        $^{208}\text{Pb}/^{204}\text{Pb}$   
 0.024%            0.036%            0.044%

Correlation coefficient of the errors is 0.91.

All of the reported results have been normalized to the nominal NBS SRM 981 Common lead standard values of Todt et al. (1996):

$^{206}\text{Pb}/^{204}\text{Pb}$        $^{207}\text{Pb}/^{204}\text{Pb}$        $^{208}\text{Pb}/^{204}\text{Pb}$   
 16.936            15.489            36.701

The results of the analyses carried out under this project, and others from the literature, are reported in Table 1.

### S-isotope analyses

The sulphur isotopic analyses were carried out at the Instituto de Geocronología y Geología Isotópica, University of Buenos Aires. Details of methodology were not made available to us. Results of analysis of the Pumahuasi samples are presented in Table 2.

### DISCUSSION

From a purely empirical point of view, on a worldwide basis, no known Sedex district is either overlain, or surrounded by, an assemblage of veins such as exemplified by the Pumahuasi vein systems.

Furthermore, the Pumahuasi veins are clearly post-tectonic (Late Ordovician?) as they cut both

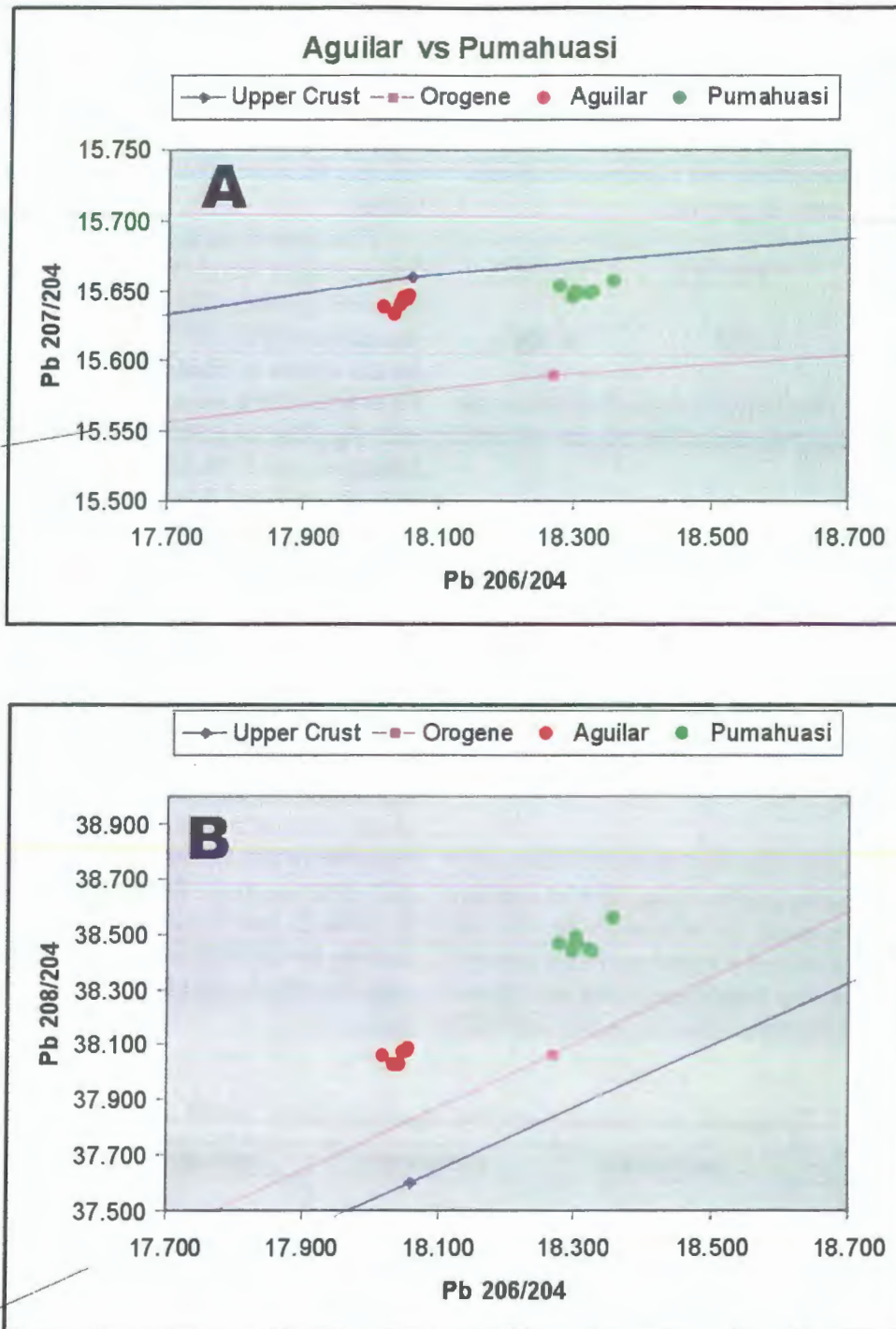
bedding and cleavage. Thus, to effect sulphide mobilization during the tectonic event represented by the folding and cleavage, an Early Ordovician sulphide (i.e., a Sedex deposit) must somehow be kept immobile during deformation, only to be released into post-tectonic fractures. We consider this scenario to be unlikely.

If, as mentioned previously, the Pumahuasi vein material were simply mobilized from a deposit similar to Aguilar, the lead isotopic composition should be essentially the same as the Aguilar galeña. As shown in Figure 2, however, the values of Pb isotopes from galenas from the Pumahuasi veins and Aguilar deposit are distinctly different. Moreover, the Pumahuasi leads show no evidence of lying along a mixing line with Aguilar leads as one end member.

The argument for the S-isotope compositions is similar to that for the Pb-isotopes. The observed values for the galena and barite from Aguilar are distinctly different from those from the Pumahuasi veins (Table 2, Figure 3). The Aguilar barite averages +30 to +35 per mil, values that are similar to the values for lower Ordovician seawater sulphate (Claypool et al., 1980), whereas the sulphide values range from about +10 to +25 per mil. The values for galena and barite from the Pumahuasi veins are significantly different from those from Aguilar materials (Figure 3, Table 2) and there is no known mechanism to account for this difference if the Pumahuasi sulphide were directly derived from an Aguilar-type sulphide mass.

Table 1: Compilation of Pb isotope analyses of galena, Aguilar deposit and Pumahuasi veins.

Occurrence	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$	Source
<b>Aguilar deposit</b>				
Mean of 19				
	18.038	15.636	38.015	Gemmell et al. (1992)
	18.017	15.639	38.061	McFarlane et al. (1990)
	18.033	15.633	38.027	Zentilli et al. (1988)
	18.047	15.645	38.078	Zentilli et al. (1988)
	18.051	15.644	38.073	Zentilli et al. (1988)
	18.053	15.647	38.087	Zentilli et al. (1988)
<b>Pumahuasi veins</b>				
Pumahuasi	18.277	15.654	38.467	This Study
Mina Olga	18.357	15.657	38.561	This Study
Alumbro-Tusca	18.322	15.648	38.441	This Study
La Belgica	18.296	15.645	38.437	Puig (1988)
La Belgica	18.305	15.649	38.474	Puig (1988)
Pumahuasi	18.300	15.650	38.460	Zentilli et al. (1988)
Cari Casini	18.301	15.648	38.490	Zentilli et al. (1988)
Gigante	18.328	15.649	38.436	Zentilli et al. (1988)



**Figure 2:**  $^{207}\text{Pb}/^{204}\text{Pb}$  vs  $^{206}\text{Pb}/^{204}\text{Pb}$  (a) and  $^{208}\text{Pb}/^{204}\text{Pb}$  vs  $^{206}\text{Pb}/^{204}\text{Pb}$  plots for galenas from the Aguilar deposit and Pumahuasi-type veins with reference curves of Zartman and Doe (1981). The similar positions in (A) relative to the Upper Crustal reference curve suggests that the Pb was derived from the same crustal rocks but at different times

If, as it appears, the Pumahuasi veins are not simply mobilized Aguilar-type sulphides, what, then, do they represent?

From a geological point of view, small carbonate or quartz veins accompanied by base metal sulphides commonly occur within metamorphosed sequences, particularly black shale, because of its propensity to accumulate high contents of trace metals. The onset of regional metamorphism results in the liberation of

potential vein components from the surrounding rocks and which are then free to migrate locally to suitable dilatant structures to form veins. We believe that the observed Pumahuasi-type veins result from this type of mechanism. In fact, the proximity of the Pumahuasi lead composition to the upper crustal evolution curve (Figure 2) and the more radiogenic character of the lead clearly suggests the Pumahuasi lead was likely derived, separately, from the same sedimentary rock

**Table 2:** S-isotope analyses, Pumahuasi veins (Aguilar values from Gemmell et al., 1993).

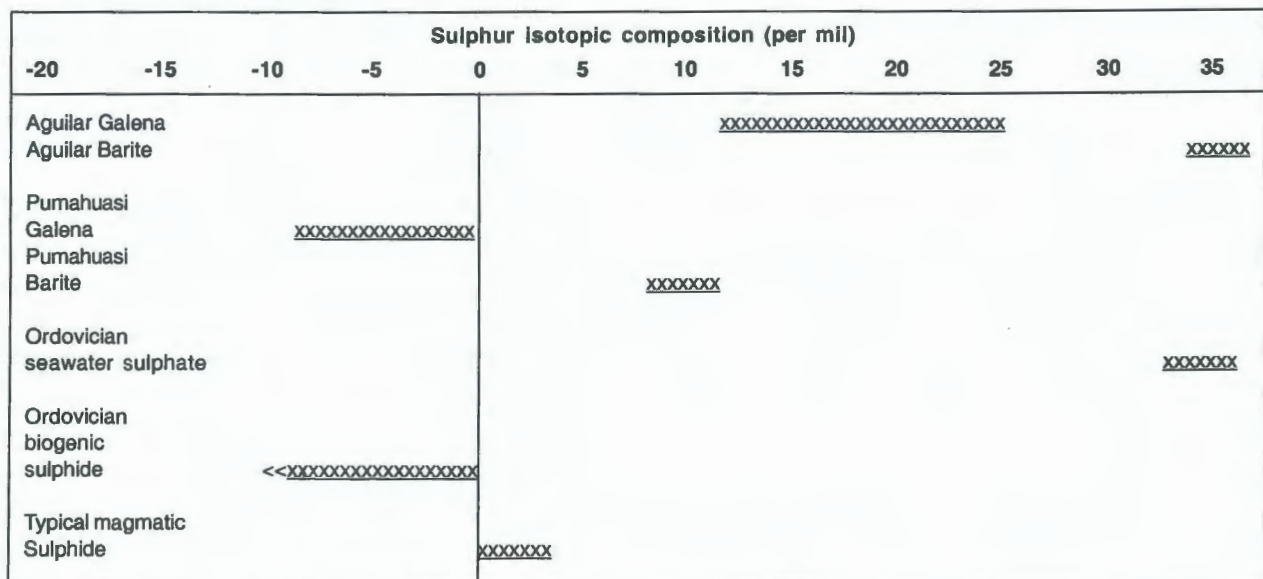
Sample	Name	Galena per mil	Barite per mil
	Aguilar deposit	Range +10 to +25	Range +30 to +35
SFB98-PU04	La Belgica, Jujuy	-1.3	
SFB98-PU05	La Pulpera, Jujuy	+0.2	
SFB98-PU07	Chocette, Jujuy	-0.6	
SFB98-PU12	La Pumahuasi, Jujuy	-4.5	
SFB98-PU13	Punta de Quivil, Jujuy		+5.8
SFB98-PU14A	Olga, Jujuy	-3.8	
SFB98-PU14a	Olga, Jujuy	-1.9	
SFB98-PU14B	Olga, Jujuy	-2.4	+9.1
SFB98-PU15	Gigante, Salta/Jujuy	-8.6	+11.5
SFB98-SAC01	Alumbro-Tusca, Salta	+4.2	+10.1

sequence as the Aguilar deposit but at a much later time.

The S-isotope values for Pumahuasi may be explained in either of two ways. The galena sulphur values between 0 and -8 per mil (average = -2) are similar to values of pyrite and pyrrhotite in lower Ordovician black shale (A. Sangster, unpublished data) in the Appalachian fold belt of eastern Canada (shown as "Ordovician biogenic sulphide" in Figure 3). In the absence of S-isotope data of Acoite Formation accessory sulphides, if this range is taken as typical of accessory sulphides in Ordovician black shales in general, then a simple mobilization of this sulphide material into veins could conceivably produce the resultant Pumahuasi sulphide values illustrated in Figure 3.

The mechanism described above, however, would not account for the +5.8 to +11.5 per mil values (ave-

rage = +9) of Pumahuasi barites (Figure 3). To effect this, an entirely different process must be invoked. One possibility is to conceive of a hydrothermal fluid, possibly, but not necessarily, originating from the Miocene igneous intrusions in the Pumahuasi area, containing sulphate of approximately the +9 per mil average of the Pumahuasi barites. In the absence of fluid inclusion data of Pumahuasi material, based on data from similar veins elsewhere in the world, an assumed temperature of about 200°C would not be unreasonable. At this temperature, the thermal fractionation between sulphate and sulphide is about 15 per mil. Thus, taking into account natural variations in fractional equilibrium and depositional temperatures, a hydrothermal fluid, containing sulphate of about +9 per mil and fractionated approximately 15 per mil, would, upon cooling, precipitate barite of approximately the same isotopic composition (i.e., +9



**Figure 3:** Aguilar and Pumahuasi deposit galena and barite sulphur isotopic compositions with some reference values.

per mil) together with sulphides of about -6 per mil, values which fall within the range of Pumahuasi vein material (Figure 3).

## CONCLUSION

Based on the geological, Pb-isotopic and S-isotopic evidence presented here, there is no support for the premise that the Pumahuasi veins were mobilized from a nearby, undiscovered Sedex sulphide mass. It is important, however, to note that this conclusion does not preclude the possible existence of a Sedex deposit in the Pumahuasi area, simply that the veins are not a direct indication of its presence. Sedex exploration must still be carried out using normal exploration methods.

Rather than being derived from an underlying Sedex sulphide body, Pumahuasi veins appear to be the product of a much later, separate, hydrothermal event in which the vein components were scavenged from the same sedimentary host assemblage, possibly by a hydrothermal fluid associated with younger intrusions.

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