APPENDIX 1

THE GEOLOGY AND ECONOMIC POTENTIAL OF THE CENTURION HIGH

Northeastern Paraguay

N.O. Willoughby

November 1979

Anschutz Corporation

Asuncion, Paraguay

TABLE OF CONTENTS

INTRODUCTION

During the course of the northern Precambrian mapping/ prospecting program carried out by Anschutz Minerals, based at Estancia Los Manantiales (east of Concepcion), a fly camp was established on Estancia Centurion from July 29 to August 7, 1979, in order to map and prospect for mineralization in the Centurion topographic high. The area was subsequently mapped at a scale of 1:60,000 using air photo coverage for control.

Logistically, a fuel cache for a Hughes 500-D Helicopter was based on the Estancia. Two crews, each consisting of one geologist and one trainee or assistant, were transported by the helicopter to and from various traverse localities. The helicopter was based at Los Manatiales.

The personnel involved were:

N. O. Willoughby	-	Geologist, MPH Consulting Ltd.
G. A. Tremblay	-	Geological Engineer, MPH Consulting Ltd.
Suk-Ho Kang	-	KECO/Trainee, Anschutz Minerals
German Aranda	-	Field Assistant, Anschutz Minerals

The mapping and prospecting operation was directed by N.O. Willoughby of MPH Consulting Ltd.

LOCATION AND ACCESS

The Centurion topographic high is located on the Rio Apa and to the south between latitudes 22°30'S and 22°10'S and between longitudes 57°30'W and 57°45'W.

Although the area is accessible by gravel and dirt road from Concepcion north through Loreto, Estancia San Luis and Estancia Primavera or Estancia Recife, the general conditions north of Rio Aquitaban/ are extremely poor. The best access is by helicopter or light fixed-wing aircraft to the grass airfield on Estancia Centurion.

PREVIOUS WORK

The area was mapped on a reconnaissance basis; also with the aid of 1:60,000 scale airphotos, by M.D. Druecker in January, February and later in June 1978.

GEOLOGICAL SETTING

The area consists of a variety of low-grade metasediments and interbedded metavolcanics intruded by hornblende granite and alkali-feldspar porphyry. The high is bounded to the east by the Precambrian basement gneisses and granites, which is apparently a fault contact. To the south and west it is overlain unconformably by arkosic sandstone and crystalline limestone, which strike approximately NNE with a moderate dip to the west.

The high has the form of a roughly elongate rectangular block about 40 km long and about 18 km wide. The block is apparently uplifted with respect to the Precambrian basement. Although the age relationship of the high to the basement is not accurately known, the generally more extreme topography and better overall rock exposure of the Centurion indicates a later age than the more poorly exposed basement rocks.

GEOLOGY

Lithological Units

The lithological units are presented in their relative stratigraphic sequence:

UNIT 1 - Interbedded:
Metaquartzite
Quartz-Sericite Schist
Phyllite, Phyllitic Schist
Metamorphosed Sub-Feldspathic Sandstone

UNIT 2 - Includes the Lithologies of Unit 1 with
Interbedded:
Pebbly Metaquartzite
Metavolcancis
Prophyroblastic Metavolcanic
Aphanitic Metavolcanic
Tuffaceous Metavolcanic

UNIT 3 - Metavolcanics
Feldspar Porphyry
Intermediate Metavolcanic

UNIT 4 - Interbedded:
Quartz-Sericite Schist and Sericite Schist
Metaquartzite
Phyllite and Phyllitic Schist

UNIT 4-a - Massive Metaquartzite

UNIT 5 - Massive to Slightly Foliated Hornblende Granite

UNIT 5-a - Foliated Biotite Granite and Leuco Granite

UNIT 6 - Strongly Schistose Feldspar Porphyry

UNIT 6-a - Feldspar Porphyry

UNIT 7 - Arkosic Sandstone

UNIT 8 - Recrystalline Limestone

Lithological Descriptions

UNIT 1

METAQUARTZITE is a medium grained white to pink and occassionally light grey and light grey-green colored rock. It weathers black and dark grey. Locally, the rock contains up to three (3) percent of finely disseminated flecks and sub-rounded granules of red brown hematite. Fledspar content varies from 0 to 5 percent. The rock is slightly to more frequently well foliated; the former being more massively recrystalline.

QUARTZ-SERICITE SCHIST is fine to medium grained. It is pink in color, weathering dark pink and pinkish brown. It is feldspathic in places with occasional development of feldspar porphyroblasts.

PHYLLITE, PHYLLITIC SCHIST generally occur as very poor exposures. They are fine to very fine grained, pink to buff and white colored rocks, weathering pink to buff and brown. They often contain rounded to elliptical (oriented parallel to schistosity) quartz porphyroblasts.

METAMORPHOSED SUB-FELDSPATHIC SANDSTONE is medium grained, white and light grey in color, weathering grey. The rock is schistose and porphyroblastic with up to 20 percent of the rock containing subrounded grey blue quartz, with lesser white to reddish hematite coated feldspar and translucent quartz porphyroblasts. The matrix consists of 75 percent quartz, 10 percent feldspar, 1-2 percent muscovite, 1-2 percent biotite. Both relic bedding and cross-bedding are present.

UNIT 2

PEBBLY METAQUARTZITE is in general a medium grained rock with 30 percent modal rounded 2-3 cm diameter quartz pebbles or porphyroblasts. The rock is white to light grey in color, weathering light grey and light grey-green. It often exhibits graded bedding.

METAVOLCANICS form relatively thin layers (5-10 m thick) apparently lenticular and interbedded or possibly intercalated with the metasediments of this unit.

Porphyroblastic Metavolcanic

This rock is fine-grained to aphanitic, light green to light grey green and light purplish grey in color. On weathered surfaces, it is black to light grey green and white. It is schistose to strongly schistose and porphyroblastic (10-15 percent of the rock). The main porphyroblast is idioblastic to subidioblastic pink feldspar, occassionally zoned with pink rims and white cores. Lesser dark green amphibole and quartz also occur as porphyroblasts. At one locality, this rock is closely associated with an amygdaloidal volcanic containing rounded quartz amygdals.

Aphanitic Metavolcanic

This rock is light green to grey and light pink in color weathering dark grey green, dark green and brown to black. It is strongly schistose in places. It contains pink to red irregular-shaped oxidation patches on the order of several tens of centimeters square in area. This suggests a solution oxidation process probably controlled by the inherent strong schistosity of the rock.

Tuffaceous Metavolcanic

This rock is light grey green in color weathering grey and dark grey. It contains up to 15 percent rounded quartz crystal clasts and angular and fragmented feldspar and amphibole or pyroxene crystal clasts.

UNIT 3 - METAVOLCANICS

Meta-Feldspar Porphyry is dark grey to grey in color on both fresh and weathered surfaces. It is foliated to schistose, highly sheared and strongly silicified. The ground mass is aphanitic and in places colored reddish brown (volcanic glass?).

Intermediate (?) Metavolcanic is dark green and green to dark grey green in color on fresh and weathered surfaces. It is aphanitic to fine grained intergranular occassionally porphyroblastic with altered porphyroblasts, probably feldspar breaking down to greenish sausserite/epidote. The rock is schistose and also strongly silicified.

As a unit, this rock forms two layers approximately 5 m thick within the more dominant meta-feldspar porphyry (Unit 3 - 1).

UNIT 4

QUARTZ-SERICITE SCHIST is a fine to medium grained rock, pink to buff or light grey to white in color weathering reddish pink to light grey green and black. This variation reflects pink sericite and light green sericite content of the respective rocks. Feldspar occassionally may be identified.

Occassionally, thin bands of hematite-specularite form exceptional S_2 foliations at a small angle with S_1 metamorphic foliation at several localities. Irregular masses and disseminated cubes of hematite (altered pyrite?) constitute up to 15 percent of the rock. Thin fractures are often hematite coated.

Closely associated with this rock is sericite schist forming thin beds within the quartz rich schist. It is very fine grained, light grey to cream colored, weathering green to brown. It also is hematite banded in places.

METAQUARTZITE is fine to medium grained, white to pink and reddish pink in color. It weathers brown to red brown and dark grey to black. A light grey variety contains up to 5 percent grey-blue quartz pebbles or blasts and infrequently smoky quartz blasts. It may be sericitic in places. Crossbedding was observed in a number of exposures.

UNIT 4-a - MASSIVE METAQUARTZITE is fine to medium grained weakly foliated rock. It is pink to white and buff in color, weathering the same and brown and black. It is pebbly in places with minor crossbedding. At a few localities, blue-grey and smoky quartz imparts a banding to the rock. It is sericitic in places.

UNIT 5 - HORNBLENDE GRANITE

This intrusive rock is medium grained subhedral to anhedral granular, massive to partly foliated. The rock is light pink to pinkish buff colored, weathering grey to black. It frequently contains up to 5 percent or less phenocrysts of mainly anhedral chloritized hornblende with lesser pale turquoise green subhedral to anhedral rounded, in part zoned, feldspar (Plagioclase?). Occassionally, reddish pink potassic feldspars form subhedral phenocrysts.

The remainder of the rock consists of 60 percent K-spar, 35 percent quartz, < 5 percent plagioclase plus traces of smoky quartz, hornblende and magnetite.

The rock is commonly sheared and it is common to find a fine grained, reddish pink equigranular and anhedral granular leucocratic granite parallel to shear. The rock is ubiquitously traversed by subparallel fractures parallel and oblique to the direction of shearing and consequently probably is a granulation and dynamic recrystallization of the hornblende granite. An intrusive relationship with the coarser granite is lacking.

UNIT 5-a - FOLIATED BIOTITE GRANITE AND LEUCO GRANITE

These rocks are found to the south intruding metaquartzite and quartz-sericite schist. The dominant rock is a fine to medium grained foliated chloritized biotite granite. The rock is pink and weathers pink and brown to black. Pink to white fine grained leuco granite is pink to white in color on fresh and weathered surfaces. It is anhedral granular containing traces of a chloritized mafic.

UNITS 6, 6-a - SCHISTOSE FELDSPAR PORPHYRY AND MASSIVE FELDSPAR PORPHYRY - These rocks are dark grey green and dark green in color with white to greyish green, occassionally zoned fledspar phenocrysts. The massive to slightly foliated feldspar porphyry is apparently intrusive into the more shear foliated and schistose metamorphosed rock. Quartz is an occasional phenocryst. A dike of feldspar porphyry occurs within hornblende granite east of Estancia Centurion.

UNIT 7 - ARKOSIC SANDSTONE is white to light grey and light pink in color on fresh and weathered surfaces. It consists of up to 30 percent subangular to subrounded feldspar, the remainder mainly subangular and subrounded quartz.

UNIT 8 - RECRYSTALLINE LIMESTONE is a dark grey massively bedded rock, equigranular and totally recrystalline. It weathers grey and dark grey. It is commonly stylolitic with sutures infilled by calcite and/or hematite.

STRUCTURAL GEOLOGY

Major Faults/Lineaments

The Centurion High is structurally dominated by two obvious fault directions. This is a NNW to SSE fault system which is truncated and offset by a younger, equally pronounced NW to SE fault system. Of lesser importance is a NE to SW fault system also truncated and offset by the NW to SE system. All three are particularly noticeable in the west where they have offset arkosic sandstone and limestone beds.

A major north-south photo lineament or fault occurs at the eastern edge of the high. This, together with the northwest

lineations east and west of the road extending south of Estancia San Luis, apparently separate the basement rocks from the Centurion lithologies and suggests at least an eastern uplift of the block with respect to the basement.

No fault planes were detected and are assumed to be vertical.

Structures Due to Granite/Porphyry Intrusive Mechanism

A complicated array of concentric and radial faults occur in the metasediments surrounding the intrusive rocks. The attitude of the country rock is characterized by steeply dipping foliation (relic bedding) away from the intrusive and by a semicircular pattern of foliation strike within the immediate vicinity of the intrusive. These characteristics conform to the mechanisms of forceful plutonic injection.

Thrust and Normal Faulting

A thrust fault within metasediments occurs south of the granite intrusive. The attitudes of foliation are considerably gentler west of the fault trace as the western portion was thrust over the steeply dipping pseudo-bedded metasediments to the east.

The mechanism may have been initiated by a later intrusion of granite or porphyry. The fault trace apparently offsets the major NW-SE fault traversing the center of the intrusion which suggests the thrust fault to be the younger. This fault also truncates and offsets a number of other faults within the metasediments.

To the northwest of the area a section consisting of Units 1 and 2 is uplifted along a NW-SE striking normal fault

with respect to the units to the south. This fault also truncates and offsets a number of other faults within the metasediments.

Shearing

The entire area is strongly fractured and sheared. Pervasive shear foliation is best observed in the metasediments, metavolcanics and hornblende granite. Closely spaced fracture cleavage occurs in some of the metavolcanics and schists and especially in the schistose feldspar porphyry unit (6).

Accompanying shearing are invariably silicification and granulation. Hematization along fracture planes is also typical, especially within the metasediments.

Quartz veining, brecciation and lesser slickensides occur in a number of fault and shear zone traces, especially a 200 m wide fault zone east of Estancia Centurion.

REGIONAL FOLIATION

Regional Foliation of the lithologies in the Centurion High are remarkably consistent, striking from about 330° to 070°. Several types of foliation are recognized and all are subparallel. They are:

Regional Metamorphic Foliation
Relic Bedding
Shear Foliation
Fracture Cleavage Foliation

FOLDING

No obvious macroscopic folding occurs in the area. Although regional metamorphism has imprinted the same and consistent

foliation on all the rock units, irregularities occur in the northern uplifted block. It is possible that these units form a broad synform which has fractured along the synformal axis. This is represented by the major N-W to NNW-SSE fault trace through the center of the block.

To the southwest of Estancia San Luis, the metasediments of Unit 4 trend NE-SW abuting against an E-W fault. The unit continued south of the fault, trending about NNW-SSE. This fault may also represent a fracture along a fold axis. The foliation or relic bedding of the unit south of the fault, if it is a fold limb, dips to the southwest and to conform to the northern limb, would necessarily be overturned.

A number of mesoscopic S_2-folds occur in the phyllites of Unit 4 east of Estancia Centurion and southwest of Estancia San Luis.

LITHOLOGICAL RELATIONSHIPS

The central NNW-SSE striking fault located close to the Apa River in the north of the area separates Unit 1 which is underlain by Unit 2 to the west of the fault and Unit 1 underlain by Unit 3 in the east. It may be that Unit 2, metasediments plus interbedded metavolcanics, is the eastern limit of volcanism and, as such, is intercalated with the metasediments.

Unit 3 is apparently overlain by Unit 4 conformably. Unit 4-a is a marker horizon within Unit 4.

The contact between the hornblende granite and the metasediments is apparently intrusive, although there is no evidence of contact metamorphism. Schistose feldspar porphyry is apparently contemporaneous or just later than the granite.

However, the contact between the two is a fault though this may be a later development. Massive feldspar porphyry is intrusive into the older metavolcanic and hornblende granite.

The arkosic sandstone and crystalline limestone overlie the Centurion lithologies unconformably.

METAMORPHISM

The regional metamorphic grade of the Centurion High rocks is very low. This is evidenced by the retention of graded and crossbedding in most of the metasediments, the preservation of phenocrysts and, in places, intergranular textures of the porphyries and metavolcanics, and the relative friability of meta-subfeldspathic sandstone, quartz-sericite schist and phyllite. Plus, the mineral assemblages do not vary to any degree.

Hornblende granite and massive feldspar porphyry (6-a) is apparently untouched by regional metamorphism. Chloritization of hornblende may be incipient metamorphism.

It is apparent that the crystalline limestone was affected by a later regional metamorphism.

Dynamic metamorphism has been important to the area. This is attested to by the shear foliation, fracture cleavage and slickensides which occur in the metasediments, metavolcanics and schistose feldspar porphyries. Granulation along zones of shear in the hornblende granite are also dynamic effects.

TECTONIC HISTORY

The Tectonic History of the area is summarized.

Deposition and volcanism of Unit 1 through to Unit 4, in that order. The sediments apparently derived from older sediments as they are relatively mature.

Minor folding of the sediments and volcanics; initial low grade regional metamorphism, development of S_2 - foliation in phyllitized sediments.

Intrusion of hornblende granite affecting the tilting and radial and concentric faulting of the metasediments and metavolcanics probably partially a solid intrusion as no evidence of contact metamorphism; or masked by later metamorphism.

Granite followed very shortly or contemporaneous with first generation of feldspar porphyry.

Low-grade regional metamorphism accompanied by regional shearing and faulting of all units. Silicification, minor hematization of fault/shear planes in metasediments, metavolcanics, and metafeldspar porphyry. Shearing and granulation within hornblende granite; a later massive silicification (saturation) of Units 3, 4 and 6 in places.

Younger intrusion of massive feldspar porphyry; dikelets intrude hornblende granite. Also, biotite granite and leuco granite to south.

Uplifting of northern block or Units 1 and 2. Then regional NNW-SSE faulting followed by NE-SW faulting. Thrust fault in Unit 4.

Low-grade regional metamorphism slightly foliated feldspar porphyry and recrystallization of limestone.

Final NW-SE faulting; E-W fault to south and N-S fault bounding the high to the basement.

Younger intrusion of phonolite.

RADIOMETRIC ANOMALIES

A number of airborne radiometric anomalies were investigated during the course of ground prospecting and mapping. The anomalies are superimposed on the geology on the 1:60,000 scale map airborne radiometrics, ground scintillometer readings and rock samples site location map.

There are five major areas of radiometric interest in the area. The anomalies are related to differences in rock type, and, in a number of cases, topographic highs.

The northern most area (Area No. 1) consists of a generally higher than background potassium anomalous area of elliptical character trending NW to SE. Also, approximately elliptical in shape and trending N-W, superimposed over the above area, is an uranium and two thorium higher than background anomalies. The area anomaly conforms to the rock Units 1 and 2, i.e., slightly feldspathic metasediments plus intercalated alkalic metavolcanics (fledspar porphyries).

On the ground, schistose aphanitic metavolcanics (Unit 2-b) were located (Sample No. 8511) which yielded radiometric values of up to 1,750 cps, total count scintillometer. The high values are consistent along strike. A spectrometer survey was carried out and all potassium, thorium and uranium values are about two times background.

The uranium/thorium ratio anomaly in this area was not located.

Area No. 2 is an extensive approximately circular potassium higher than background anomaly covering the hornblende granite and feldspar porphyry. The large uranium and thorium anomalies in the east of this area are correlative with the topographically high, well-exposed hornblende granite. The uranium and three thorium anomalies west of the granite correlate with the younger feldspar porphyry intrusives, which are also topo highs and good rock exposure.

The two uranium/thorium ratios in the area were not located on the ground.

Anomaly Area No. 3 is a potassium and thorium anomaly roughly following the trend of the metavolcanics of Unit 3 and metasediments of Unit 4. It is probable the anomaly reflects the potassic rich metavolcanic unit which also underlies Unit 4.

The phonolitic plug intruding metaquartzite to the east is covered by the uranium and thorium anomaly of Area No. 4. The southwestern extension of the anomaly may reflect subsurface alkalic rocks related to the phonolite. No rock exposure was found southwest of the phonolite.

Area No. 5 is a thorium anomaly within metasediments of Unit 4 intruded by a gneissic biotite granite and leuco granite. On the ground, an exposure of sheared and silicified, in part hematized metaquartzite and pebble metaquartzite, yielded 4,000 cps in total counts on a scintillometer. Subsequent investigation using a GS-410 Spectrometer gave very high values in thorium, whereas potassium and uranium were only slightly above background. Whole rock analyses of samples from this locality (8501, 8502) are pending.

The increase in potassium background just to the southeast of the area reflects the now exposed basement gneisses and granites.

ECONOMIC POTENTIAL AND CONCLUSIONS

During the course of prospecting and mapping of the Centurion High, four models or uranium mineralization were considered possible. These are:

Granite/Pegmatite Zoned Type
Beverlodge Type (Fracture Fill)
Unconformity Type
Carbonatite Type

GRANITE/PEGMATITE ZONED TYPE

No pegmatite bodies occur within the Centurion High. The hornblende granite intrusive is a massive body with relatively low radioactivity. (Average 250 cps, total count Scintillometer). Although the rock is faulted and strongly sheared in places, no late stage mineralization aside from minor silicification and quartz veining occurs. The faulted quartz breccia and veining in the northeast portion of the granite contains minor hematite along fracture planes. It is not radioactive.

BEVERLODGE TYPE (FRACTURE FILL)

The Beverlodge Deposit consists of fracture and fault controlled uranium mineralization within a variety of metasediments and metavolcanics accompanied by extensive feldspathization, chloritization, silicification and hematization of both the sheared rocks and the surrounding rocks. The metasediments are derived from mainly impure sands; greywackes, wackes, arkoses plus their calcareous equivalents and pelitic rocks. The grade of metamorphism is lower to middle greenschist.

Although the Centurion High has a variety of fractured and sheared metasediments and metavolcanics, three characteristics of the Beverlodge Type of deposit are lacking.

The sediments in the Centurion High are more mature quartz sands and siltstones. No pelitic rocks occur; the phyllites being highly siliceous and sericitic lacking the initial potential sedimentary reducing environment for uranium precipitation.

Extensive alterations of the country rock adjacent to faulting and shearing do not exist. Minor hematization and more extensive silicification occur in fault/fracture planes, but these zones fail to exhibit <u>any</u> mineralization, including pyrite, i.e., mineral rich hydrothermal solutions are lacking. There is only <u>one</u> case where fractured and sheared metasediment yield high total counts, namely the anomaly found in Area 5, which is now attributable to thorium. Elsewhere, the radioactivity is consistently low.

The grade of metamorphism is very low at Centurion.

<u>UNCONFORMITY TYPE</u>

Although the Centurion metasediments are apparently younger than the eastern basement complex, no near surface unconformity exists. It is also apparent that the Centurion-basement "contact" is a fault contact. There is no airborne radiometric anomaly or ground evidence of mineralization at this interface.

<u>CARBONATITE TYPE</u>

No carbonatite bodies occur in the area although there is a small alkalic plug northeast of Estancia San Luis. This body

falls within the airborne anomaly area No. 4. The anomaly undoubtedly is the subsurface expression of this body. There is still the possibility that the anomaly represents a subsurface carbonatite and hence may warrant further investigation.

The Centurion High, for the reasons outlined above, has a low potential for uranium mineralization. Although the porphyries and metavolcanics suggest hosts for base metal mineralization, the overall lack of mineralization, especially pyrite, and lack of evidence of hydrothermal processes certainly invalidate economic possibilities in this respect. The metavolcanic Unit 3 underlying the metasediments Unit 4 has yet to be tested. Geochemistry and airborne EM surveys are required in this case to delineate any possible economic sources.