

Multinational Andean Project (MAP): Geological co-operation across borders

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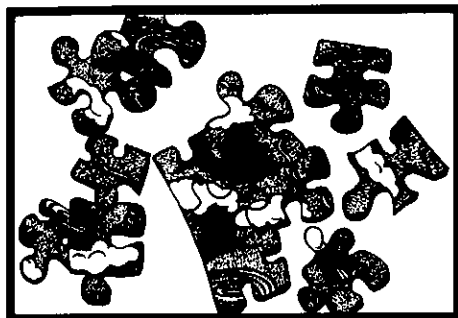
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Article abstract

One of the world's largest and most spectacular continental areas of rhyolitic-andesitic volcanic rocks, the Neogene-Quaternary central Andes volcanic complex, occurs in the high Andes mountains of South America. More than 1000 eruptive centres, many hosting significant mines and occurrences of epithermal precious metals, as well as other metals and industrial minerals, underlie the Andean border regions of Argentina, Bolivia, Chile, and Peru. Many mining companies are actively exploring the area, including a large number of Canadian-based companies. The Multinational Andean Project (MAP), funded by the Canadian International Development Agency and the national governments of Argentina, Bolivia, Chile, and Peru and facilitated by the Geological Survey of Canada, is an important international initiative for Canada in terms of scientific exchange and fostering enhanced relationships between Canadian and South American national geoscience agencies and mineral exploration companies. Now in the final year of the five year project, MAP will have a long lasting scientific legacy in the form of geological and metallogenic maps consistent across international boundaries, a multicountry analytical geochemical data base, petrological reference materials for Andean volcanic rocks, extensive geophysical survey information, and scientific publications. The high level of co-operation established among the participating countries provides an excellent model for future international projects.



Multinational Andean Project (MAP): Geological co-operation across borders

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SUMMARY

One of the world's largest and most spectacular continental areas of rhyolitic-andesitic volcanic rocks, the Neogene-Quaternary central Andes volcanic complex, occurs in the high Andes mountains of South America. More than 1000 eruptive centres, many hosting significant mines and occurrences of epithermal precious metals, as well as other metals and industrial minerals, underlie the Andean border regions of Argentina, Bolivia, Chile, and Peru. Many mining companies are actively exploring the area, including a large number of Canadian-based companies. The Multinational Andean Project (MAP), funded by the Canadian International Development Agency and the national governments of Argentina, Bolivia, Chile, and Peru and facilitated by the Geological Survey of Canada, is an important international initiative for Canada in terms of scientific exchange and fostering enhanced relationships between Canadian and South American national geoscience agencies and mineral exploration companies. Now in the final year of the five year project, MAP will have a long lasting scientific legacy in the form of geological and metallogenic maps consistent across international boundaries, a multicountry analytical

geochemical data base, petrological reference materials for Andean volcanic rocks, extensive geophysical survey information, and scientific publications. The high level of co-operation established among the participating countries provides an excellent model for future international projects.

RÉSUMÉ

En Amérique du Sud, dans les Andes, se trouve l'une des plus grandes et des plus spectaculaires régions continentales de roches rhyo-andésitiques, soit le complexe volcanique Néogène-Quaternaire des Andes centrales. Situé à la frontière andine de l'Argentine, de la Bolivie, du Chili et du Pérou, ce complexe comporte plus de 1 000 centres d'éruption, beaucoup de ceux-ci renfermant des gisements ou des mines hôtes de type épithermal de métaux, précieux et autres, ou de minéraux industriels. De nombreuses sociétés d'exploration minière y sont très actives et une bonne proportion d'entre-elles sont d'origine canadienne. Financé par l'Agence canadienne de coopération et de développement international, par les gouvernements respectifs de l'Argentine, de la Bolivie, du Chili et du Pérou, et facilité par la Commission géologique du Canada, le Projet multinational des Andes (PMA) est un projet de collaboration internationale important pour le Canada, tant par les échanges scientifiques qu'il comporte que par ses aspects amélioratifs des relations entre les agences scientifiques nationales des pays en cause et les sociétés d'exploration minière présentes. Ce projet quinquennal, qui en est maintenant à sa dernière année, laissera un héritage durable par ses cartes géologiques et métallogéniques de facture uniforme pour cette région transfrontalière, par sa base de données géochimique multinationale, par sa banque d'échantillons pétrologiques de référence sur des roches volcaniques des Andes, par d'importantes informations tirées de levés géophysiques, ainsi que par des publications scientifiques. Le fort degré de coopération établi entre les pays participants constitue un excellent modèle en vue de coopérations internationales à venir.

INTRODUCTION

The central Andes volcanic complex, covering about 300,000 km², is one of the world's largest continental areas of felsic to

intermediate (rhyolitic to andesitic) volcanic rocks. This mountainous area of rugged relief hosts more than 1000 eruptive centres — stratovolcanoes, calderas, volcanic-dome complexes, and other volcanic landforms — and many of these eruptive centres have genetically related hydrothermal alteration zones and associated epithermal precious metal deposits (Fig. 1) (Ericksen and Cunningham, 1993a,b). Although many precious metal deposits were first described and worked during Spanish colonial times, at least a dozen major deposits have been discovered since the 1970s (Ericksen and Cunningham, 1993a,b). In addition to precious metals, other types of deposits have been important economically in this region as well, including Cu, Sn, Zn, Pb, Sb, W, Li, and other metals and industrial minerals. Thus many major mining companies have active exploration programs in the area at present. At the end of 1998, for example, Canadian-based companies were the leading explorationists in Argentina, Bolivia, Chile, Colombia, Guyana, and Peru, holding more than 150 mineral properties in Peru and more than 100 properties in each of Argentina, Chile, and Brazil (Lemieux, 1999).

Significant metallic mineral production and high potential in the area, combined with limited geological expertise in the South American countries in which the central Andes volcanic complex occurs, make this area ideal for co-operative geoscience projects between national South American geoscience agencies and North American geological surveys. The first of such programs was spearheaded by the United States Geological Survey (USGS) from 1990-1993, and emphasized co-operative investigation of precious-metal deposits (Au, Ag) in this young volcanic context (Ericksen and Cunningham, 1993a,b).

Canadian geoscience expertise provides an essential contribution to the Multinational Andean Project (MAP), an international co-operative scientific project jointly funded by the Canadian International Development Agency (CIDA) and the national geoscience agencies of four South American countries (Argentina, Bolivia, Chile, and Peru) and facilitated by the Geological Survey of Canada (GSC). Now in the final year of the present 5-year program (1996-2001),

MAP was derived from the previous 3-year USGS-facilitated project involving three of the four countries presently participating in the MAP project: Bolivia, Chile, and Peru. On completion of the USGS facilitated project, the Inter-American Development Bank (IDB) / Banco Interamericano de Desarrollo (BID) funded development of a new project, which later evolved into MAP. This new MAP project had an initially projected 5-year (September 1996 to December 2001) combined budget of up to about C\$13 million contributed by the participating countries, in addition to C\$4.8 million contributed by CIDA (IDB/BID 1995, MAP 1996).

HISTORY OF THE MULTINATIONAL ANDEAN PROJECT

In its formative years from 1990-1993, the initial co-operative project led by USGS personnel was titled the "International co-operative project for investigation of volcanic-hosted precious-metal deposits in the central Andes" (ICPIVPD). Its purpose was to investigate precious metal occurrences and potential in the vast and relatively unexplored, and in part poorly known, Neogene-Quaternary (25 Ma and younger) central Andes volcanic complex, along the borders of Bolivia, Chile, and Peru (Fig. 1), in co-operation with geoscientists of the participating countries. Leadership and guidance were provided by senior USGS personnel Charles G. (Skip) Cunningham and George Ericksen, who already had extensive experience in the study of similar deposits and settings. The initial 1990-1993 phase of the project also focussed on increasing the level of expertise in the national geoscience surveys of the three countries involved. The main activities consisted of professional training in the form of workshops, seminars, and technical papers. Results included a final report as well as a book of technical articles describing the study area, representing impressive progress in understanding of the mineral deposits of the area (Ericksen and Cunningham, 1993a). Other publications related to work or expertise stemming from this project include Ericksen and Cunningham, 1993b; Cunningham, 1993; Cun-

ningham *et al.*, 1996; and Ericksen, 1993.

At the final meeting of the ICPIVPD in La Paz, Bolivia, in March 1993, representatives from the Argentinian national geoscience survey (then known as Dirección Nacional del Servicio Geológico Argentina) agreed to join a proposed second phase of the program.

The Multinational Andean Program, now called the Multinational Andean Project (MAP), was initiated by an official agreement of technical co-operation among all four countries to promote and carry out regional projects, strengthen the countries' geoscience institutions, and promote horizontal co-operation among

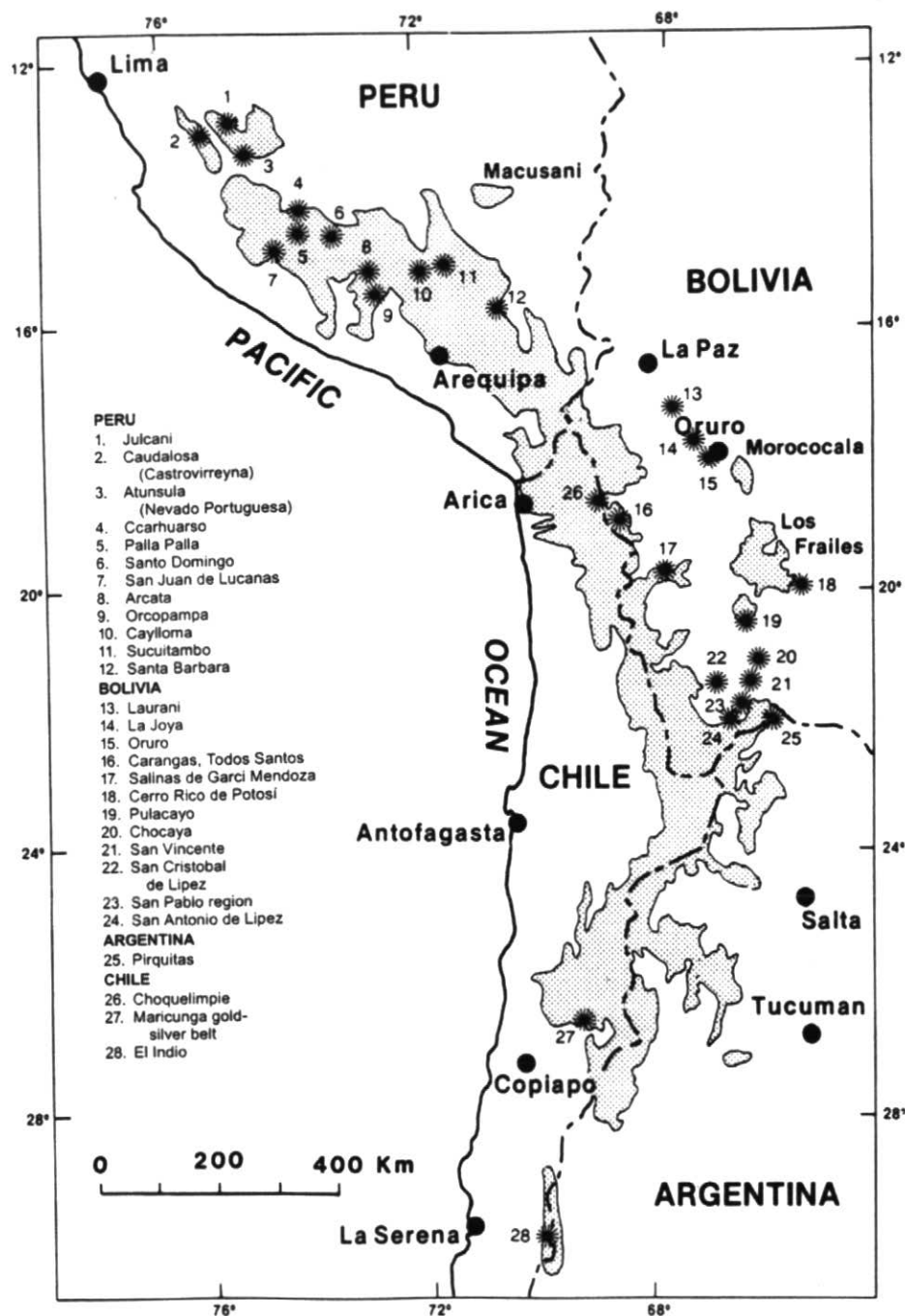


Figure 1 Epithermal precious metal deposits associated with the Neogene-Quaternary volcanic complexes in the central Andes (stippled area). Numbers refer to deposits in the countries shown as of 1993 (from Ericksen and Cunningham, 1993b; reproduced with permission of the Geological Association of Canada).

the countries, in addition to addressing environmental concerns, geologic risk, and urban geology (IDB/BID 1995).

In 1994, a team of nine specialists assembled by the GSC under contract to the Inter-American Development Bank and led by one of us (Catherine Hickson) conducted a feasibility study for the next phase of co-operative work in the Andes, producing a program proposal in January 1995 titled "Geological projects to spur economic and social development in the border regions between Argentina, Bolivia, Chile, and Peru" (IDB/BID 1995). This report outlined MAP's goals and plans, potential economic and social development, and organization of the project.

Goals of the proposed new program focussed primarily on the concept of "horizontal integration" of results and knowledge among the four South American countries involved. A shared objective and common purpose was to promote the economic and social development, in border regions of the participating nations, that should flow from the use of new geological information (IDB/BID 1995, p. 1). Both historically and geographically, the high mountainous area of the Andes bordering these countries has formed a barrier to economic and social development, although the demonstrated wealth of mineral resources in the region has continued to be encouraging. By exploring and developing geological resources and sharing scientific information, these countries would be able to improve not only regional growth and prosperity but also international relations. The intended end result would be readily available up-to-date geoscientific information that is key to attracting exploration and mining activities, and is essential for land use planning, environmental impact studies, and regional infrastructure improvement.

Although BID chose not to fund this 1995 MAP proposal, CIDA viewed it as a worthwhile project, particularly in light of the significant presence of Canadian exploration companies in the area of interest. Canada is recognized worldwide as a leader in geological field mapping as well as digital mapping technology, and in mining technology and successful mineral exploration. Accordingly, many of these companies

will benefit from the work of MAP with Canada playing a leading role. Following an initial meeting in Chile in May 1996, the project (MAP) officially began in September of that year (MAP, 1996).

GEOLOGIC SETTING OF THE MULTINATIONAL ANDEAN PROJECT AREA

The Multinational Andean Project concentrates on the high Andean border regions of four South American countries: Argentina, Bolivia, Chile, and Peru, from about 14°S to 28°S. Each country has designated an area of study adjacent to the borders, so that the main part of the MAP study area is a contiguous belt encompassing parts of all four countries, roughly coincident with the Neogene-Quaternary volcanic complex in the central Andes (Fig. 1). A few smaller areas have also been selected for particular MAP activities in other localities. Most of the MAP study area is above 3000 m elevation in the Cordillera Occidental and Altiplano-Puna physiographic belts, bordered on the east by the Cordillera Oriental; tectonically this area is east of the forearc, and west of the foreland fold and thrust belt. The curved part of the central Andean arc is sometimes referred to as the "Bolivian Orocline," because its geometric shape parallels the curve of the offshore Peru-Chile trench, and is believed to be caused by bending of the subducting Nazca plate (Isacks, 1988; Tinker *et al.*, 1996).

Uplift in the high Andes is believed to have occurred in pulses, including two major periods of crustal shortening and thickening primarily during Neogene time (27 Ma to 5 Ma; 5 Ma to present). The tectonic interrelationship between crustal deformation, volcanism, and hydrothermal deposit formation in the area covered by the MAP project is considered to require modern scientific reinterpretation in order to be better understood in terms of both geological history and economic resource development. The entire area surrounding and including MAP is extremely rich in ore deposits, not only of precious metals (Au, Ag), but also Cu, Sn, Zn, Pb, Sb, W, and other metals and industrial minerals, including the valuable alkali deposits (nitrates, borates, Li and Na salts) of the huge salars (salt lakes) of northwestern

Argentina, southwestern Bolivia, and northeastern Chile (Ericksen, 1993).

Major ore belts occur along structurally parallel trends, while many deposits themselves tend to be focussed on young volcanic centres (Fig. 2), where magma has risen through deformed Paleozoic basin strata, commonly Ordovician and Silurian shales, siltstones, and sandstones, but including Cambrian to Permian strata. Carbonate rocks tend to be less common in this area. Modern exploration strategies developed by companies with active mines and prospects in and near the MAP area are based on studies of previously defined mineral deposit environments, and may include looking for specific prospective combinations of structural features in Paleozoic sediments (such as facies changes, anti-formal structures, and intersecting fault trends) and related intrusive and extrusive domes of the Neogene to Quaternary volcanic complex. Thus renewed government geological mapping and dating studies are a particularly useful contribution of the Multinational Andean Project.

MULTINATIONAL ANDEAN PROJECT ACTIVITIES 1996-2000

Map activities to date have concentrated on four primary objectives:

- Scientific training and geological work, leading to more compatible geoscience data within the national geoscience agencies;
- Increased co-operation among all five countries (= horizontal integration);
- Enhanced institutional relationships with the private sector, especially mineral exploration and mining companies; and
- Institutional strengthening of the national geoscience agencies of Argentina, Bolivia, Chile, and Peru.

Most MAP activities have achieved progress on all four objectives. Scientific training activities have occurred in all five participating countries, and include a variety of short courses and joint field trips, with a total of well over 200 participants so far, commonly involving Canadian geological expertise (Fig. 3). MAP participants and others are kept informed of progress through the MAP Newsletter available on the web at www.pma-map.com, in addition to semi-annual meetings of the Executive Coun-

cil, made up of the heads of the national geoscience agencies and the countries' project leaders and co-ordinators, as well as GSC management staff (Fig. 4). Reports on the progress of MAP activities are produced quarterly (MAP 1996-2000).

REGIONAL GEOSCIENCE

Regional Geological Mapping and Volcanological Fieldwork

MAP regional studies including geological mapping have contributed to a better understanding of the young volcanic complex that underlies much of the project area in the border regions between the participant countries in the high Andes. Volcanological fieldwork involving teams of Canadian and South American geologists has been carried out in all four South American countries, including cross-border mapping. Field trips to share expertise, as well as joint geological mapping expeditions have increased geological knowledge in all countries involved, including Canada (Figs. 3, 5, 6). One part of a volcanological field course was given in Vancouver, Canada, with field visits to local volcanoes and volcanic complexes in British Columbia and Washington. The main complement of volcanological field training took place in Chile, with visits to Andean volcanic areas, including the active volcano, Lascar. Great emphasis has been placed on collection of geochemical and dating information to assist in making important correlations across the borders of member countries. Some of the MAP short courses have offered training not only in volcanological field mapping but also sampling techniques for radiometric dating.

Regional mapping techniques also were the focus of a study of Paleozoic stratigraphy in the Peru-Bolivia border zone. In 1997 Canadian GSC geologist Steve Gordey visited Peru to assess needs for equipment and expertise, and to present lectures on the importance of paleontology and geochronology for stratigraphic correlation, as well as techniques and concepts involved in producing regional geological synthesis maps. This was followed by field work with Peruvian geologists, focussing on producing improved geological maps that will assist the mineral exploration community. A short course involved training in up-to-date digital manipulation and

production of maps, including the use of radar satellite imagery. In 1999 and 2000, two courses focussing on mapping in volcanic terrain were given to about 60 Peruvians from INGEMMET and local universities. This short course has also been successfully presented to private industry in both Peru and Chile.

Several field programs in Argentina, Bolivia, and Peru have involved the expertise of Canadian geoscientists, including Andre Panteleyev, Paul Metcalfe, and one of us (Catherine Hickson) in volcanological mapping, as well as field study of numerous mineral showings and deposits. This work, combined with fieldwork by the national geoscience agencies in volcanology, geochemistry, and dating, is forming the foundation of a new metallogenic map of the area, as well as leading to updating of the regional geological maps.

Several new and ongoing geological mapping projects have benefitted from the MAP program. As part of their national mapping programs, all four countries have been active in publishing new geological and metallogenic map products. (See *Maps and Scientific Information of the Multinational Andean Project*, p. 125.)

Argentina

Argentina (SEGEMAR) has been very active in producing maps. These include maps (hard copy and CD-ROM) of multi-element geochemical data and data bases of mineral resources in Argentina, produced partly under the Multinational Andean Project; metallogenic and mineral resource maps at 1:250,000, especially near the border with Chile; and a metallogenic map of Argentina at a scale of 1:2,500,000 in a GIS format.

Bolivia

Bolivia (SERGEOMIN) has published several new geological maps throughout the duration of the MAP project, including thematic maps of the mineral resources of Bolivia at a scale of 1:250,000, and geological maps at a scale of 1:100,000, many of them bilingual in Spanish and English. In 1998 Bolivia published a 1:1,000,000 scale Geological Map of Bolivia, and in 1999 a 1:1,000,000 scale Metallogenic Map of Bolivia with an accompanying memoir in

Spanish. Two open file reports on geological and mining exploration of the Western Cordillera in Bolivia also have been produced directly under the auspices of MAP.

Chile

Chile (SERNAGEOMIN) has had an active program in updating and publishing geological map sheets, particularly in volcanic areas, at a scale of 1:100,000. Their MAP hydrogeological study has also contributed to an understanding of the hydrogeology of the high Andes along the borders with Argentina, Bolivia, and Peru.

Peru

Peru (INGEMMET) has made rapid advances in completing national geologic map coverage, with several new 1:100,000 map sheets published, as well as compilation maps of the entire country at a scale of 1:6,000,000, including a metallogenic map, a tectonic map, and a thematic map showing major metallogenic areas and in particular auriferous areas. Each year INGEMMET publishes an updated *Atlas of Mining and Energy in Peru*, with recent editions reflecting progress under the MAP project.

METALLOGENY AND MINERAL DEPOSIT MODELLING SHORT COURSES

Peru has been the main site for short courses on metallogenic resource evaluation and mineral deposit modelling and applications, for participants from both government and private sectors. An important goal of these courses is the training of participants so that they can contribute to the metallogenic map of the border regions of the four countries.

METALLOGENIC MAP OF THE BORDER REGIONS (1:1,000,000)

All of the new geological and mineral deposits fieldwork and publications have contributed to the major mapping product of the MAP program, a multi-country collaborative Metallogenic Map of the Border Regions between Argentina, Bolivia, Chile, and Peru, from 14°S to 28°S, at a scale of 1:1,000,000. Using agreed-upon cartographic standards and symbols, a multicountry committee under the cartographic leadership of Rob

Cocking of GSC Vancouver and the geological leadership of Eduardo Zappettini of Argentina, with representatives from all participant countries, is compiling topographic, geologic, and metallogenic information from the four countries. This involves establishing a unified stratigraphic column for the area, correlating map units across international boundaries, and deciding on which mines and mineral deposits to include on the map and in the associated data base. The map will be produced in Spanish with English translation, and accompanied by a publication. The Map of the Border Regions of Argentina, Bolivia, Chile, and Peru was designed to be the centrepiece presentation of the special MAP symposium held as part of the Chilean Geological Congress, 1-4 August 2000, and at the International Geological Congress meeting in Rio de Janeiro, Brazil, 6-17 August 2000. Maps may be obtained from Eduardo Zappettini, Buenos Aires, Argentina.

GEOCHRONOLOGY: RADIOMETRIC DATING AND ISOTOPE STUDIES

The Multinational Andean Project has been particularly successful in contributing to our understanding of the evolution of the Andes in time and space through newly determined geochronological ages. All four countries have participated in this effort, with Canada providing most of the analytical dating services, spearheaded by GSC geochronologist Mike Villeneuve in Ottawa. Different dating techniques have been attempted on different kinds of rocks, including very successful $^{40}\text{Ar}/^{39}\text{Ar}$ dating on very young (<1 Ma) volcanic and plutonic rocks; the U-Pb method using zircon separates; minor K/Ar dating; and ^{14}C radiocarbon and apatite fission track methods. Nearly 200 new radiometric dates have been determined from Andean samples during the MAP program as of August 2000, and more are in the process of being analysed. This is the first comprehensive and extensive program of argon-argon dating in the region, where prior to the Multinational Andean Project, relatively few dates had been produced in Argentina, Bolivia, and Peru. New dates from the MAP project span a widespread area in the high border regions of the four countries, an area

more than 250 km wide and 1500 km along the length of the Andean cordillera, mainly from Neogene and younger volcanic rocks, many previously undated. By the end of the MAP project, at least 100 more radiometric dates will have been completed for this area, amounting to a major geochronological contribution to Andean geology.

In addition to radiometric dating, isotopic work on common lead (Pb) has revealed information supportive of general ages in certain rocks. Other isotopic work has involved oxygen isotope analysis in conjunction with hydrogeological studies of the Chilean Andes. Most of the MAP isotopic analytical work is being done in Canada, using university geochronology labs at Dalhousie, Waterloo, and University of British Columbia, as well as the GSC's isotopic lab in Ottawa. With the help of MAP program efforts, a new $^{40}\text{Ar}/^{39}\text{Ar}$ argon dating laboratory has been successfully set up and is running in Chile, where a well-established K-Ar lab has already been operational for many years. Precise $^{40}\text{Ar}/^{39}\text{Ar}$ dating under the MAP project has been added to the Chileans' own significant number of previously derived K-Ar dates. The new Chilean $^{40}\text{Ar}/^{39}\text{Ar}$ facility produced its first radiometric date in November 1999 (Fig. 7).

PALEONTOLOGICAL AGE DETERMINATIONS

Specific age results from paleontological work under the auspices of the Multinational Andean Project have been less significant than radiometric dating, due mainly to the emphasis of the project on young volcanic centres. Paleontology is important to the cross-border correlations of folded and faulted Paleozoic basin sequences that host mineral deposits, where intruded by younger igneous and hydrothermal systems. A great deal more stratigraphic and paleontological work is recommended in these areas.

Palynological analysis of organic samples from volcanic areas has revealed an unfortunate dearth of suitably specific pollen in the samples collected to date. The few indicated ages based on available evidence are consistent with geological field observations. In places where microfossils have been investigated from Paleozoic and Mesozoic strata, they have

confirmed previously known geological ages. For example, a paleontological report by the GSC in Calgary on samples collected as part of the MAP program in Peru near the Bolivian border shows a fusulinacean fauna consistent with an early Permian (Asselian-Wolfcampian) midcontinent Andean biogeographic province, consistent with previous geological mapping of the Copacabana Group in this area.

HYDROGEOLOGICAL STUDIES

In the Copiapó area of northern Chile, a co-operative hydrogeological program, involving study of oxygen, hydrogen, and carbon isotopes, has been carried out in collaboration with scientists from the University of Waterloo (Ontario, Canada). This part of the project seeks to determine additional ground water resources for the Copiapó region.

GEOCHEMICAL AND PETROLOGICAL STUDIES

One of the long-lasting products of the MAP program is a developing extensive data base of analytical results from geochemical and geochronological laboratory procedures. Hundreds of rock samples have been analysed for major, trace, and in some cases rare earth element geochemistry. Widespread soil and stream sediment sampling has also provided countries like Argentina with significant additions to their country's regional lithogeochemical knowledge. Petrographic studies as part of the MAP program are also contributing to better characterization of rock types in conjunction with new field mapping information and the increased quantity and quality of geochemical analytical data.

One of the MAP program's innovative multicountry scientific projects is to establish a set of petrological sample standards (geochemical reference materials) for Andean rocks. All four South American participant countries have agreed on guidelines for the collection and evaluation of a set of five standards spanning a range of compositions from rhyolite to basalt in the high Andes within the young volcanic complex underlying the MAP project area. These petrological standards will be used as geochemical reference materials for monitoring the quality of future geo-

chemical analyses for petrological studies of igneous rock suites. Along with the MAP sample data base, this sample standard set will be of continuing value to scientists studying the Andean cordillera. One set of MAP geochemical reference materials has already been produced by the Ontario Ministry of Northern Mines and Development Geoscience laboratories and is being distributed to the countries, with the others to follow soon. All five countries involved — Argentina, Bolivia, Chile, Peru, and Canada — will benefit from the use of these petrological standards, as will the international geological community.

TECHNOLOGY TRAINING

MAP has been instrumental in introducing new technology to the member countries, including digital mapping hardware and software, equipment for studying fluid inclusions, Portable Infrared Mineral Analyser (PIMA), and other scientific advances. Short courses have been given to personnel from the member countries on various research and field methods, including remote sensing, FieldLog digital data capture, use of the PIMA, and use of fluid inclusion equipment.

Remote Sensing

One of the first MAP activities to be completed was a co-operative project in remote sensing in 1997, with satellite imagery training, including Thematic Mapping (TM) imaging, done in exchange between Argentinian and Canadian geologists, followed by field checking in Argentina. This work was carried

out in co-operation with another CIDA project, GLOBESar. A short course involving training in up-to-date digital manipulation and production of maps, including using radar satellite imagery, was given in Peru. Remote sensing images have also been produced of the Bolivian altiplano. Satellite imagery produced under the auspices of MAP training activities has contributed to new mapping products.

FieldLog Training

By March of 1998 all four countries had hosted successful short courses in FieldLog, a form of digital data capture, given by Canadian specialists. Thirty-two

individuals received training; required software and manuals were translated into Spanish; and appropriate equipment was donated to each country. All countries were brought up-to-date on Canadian technology and procedures designed to facilitate rapid production of digital geological maps shortly after completion of fieldwork.

Use of Portable Infrared Mineral Analyser (PIMA)

One of the most useful new tools in global mineral exploration is the PIMA, which is used for identifying alteration minerals such as alunite, kaolinite, dickite and others directly from hand specimens

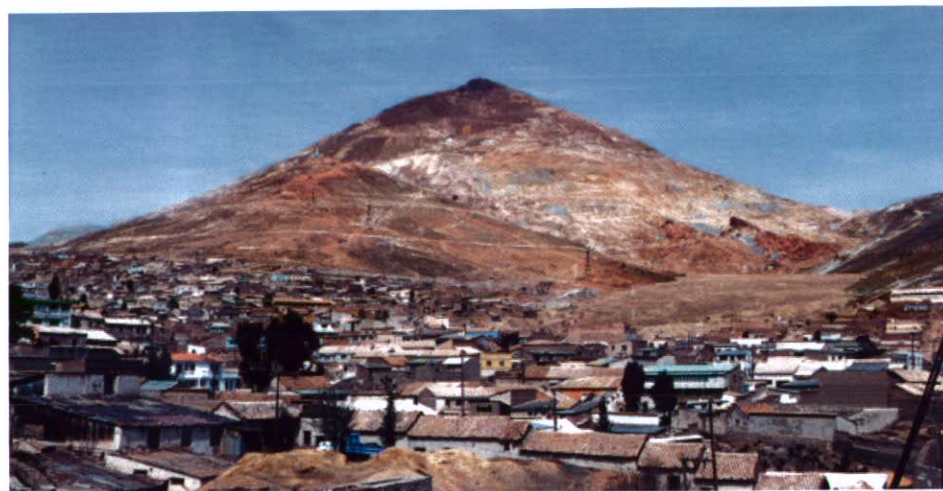


Figure 2 Cerro Rico de Potosí, Bolivia: an example of a rich metalliferous ore deposit associated with young volcanic centres in the central Andes. Cerro Rico, #18 on Figure 1, is the world's largest silver deposit, also mined for tin and zinc (Cunningham *et al.*, 1996). (Photo by J. Getsinger, 1999)



Figure 3 Canadian epithermal mineral deposit expert Andre Panteleyev marking an outcrop with orientation measurements during a field course which visited a number of mines in the MAP region (photo by C. Hickson).



Figure 4 MAP Executive Council meeting, Toronto, March 1999. From left to right: Lic. Roberto Page, Argentina; Ing. Carlos Riera, Bolivia; Ing. Ricardo Troncoso, Chile; Ing. Hugo Rivera, Peru; Dr. Catherine Hickson, Canada (photo by O. Krauth).

in the field or field office. Many Canadian and other exploration companies working in South America are using this technology to outline alteration halos around mineral deposits; for example, BHP at Agua Rica, Argentina, visited during a MAP mineral deposits field course. As part of the MAP program, Canadian experts Anne Thompson of PetraSciences Inc. and Andre Panteleyev have conducted demonstration and training sessions for geologists from all of the participating countries on the uses of the PIMA (Fig 8).

Fluid Inclusion Training

Short courses and consultation on the use of fluid inclusion research equipment



Figure 5 Participants in a Volcanology Field Course, Peru, 2000, including Cathie Hickson, front lower left.

provided with the help of the Multinational Andean Project were given in Bolivia, Chile, and Peru by Jim Reynolds and Tawn Albinson of Fluid Inc., Colorado, under the auspices of the MAP project.

Airborne Geophysical Surveys

Multinational Andean Project multi-parameter airborne geophysical surveys have been a great success, accomplishing the goals of international scientific co-operation and building relationships

between government geoscience agencies and the mineral exploration industry. Co-ordinated by GSC staff and Canadian geophysical experts, participating countries have elicited the collaboration of private sector exploration companies in aeromagnetic and spectrometry surveys that have covered or are planned to cover extensive areas straddling international boundaries in areas of mineral exploration interest in remote regions of the high Andes. The surveys cover three areas: 1) northwestern Argentina in the Puna



Figure 6 Mineral deposits field course in Argentina (El Aguilar Mine), 1999 (photo by M. Ellerbeck).

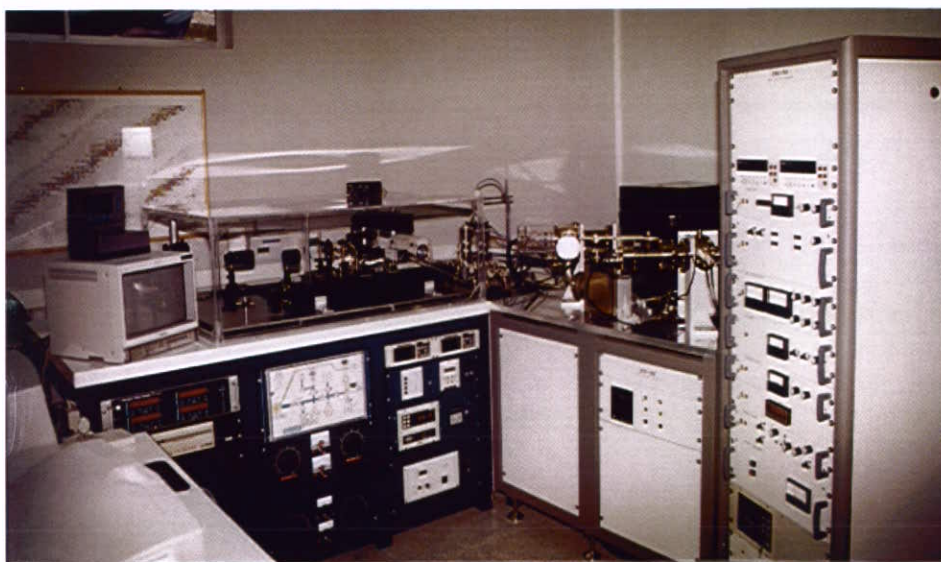


Figure 7 New argon-argon radiometric dating facility at the Chilean Geochronology Lab, which has been operating as a well-established K-Ar dating lab for years; Santiago, Chile, 1999. Set up with the help of MAP program efforts, this new part of the lab produced its first $^{40}\text{Ar}/^{39}\text{Ar}$ date in November 1999 (photo by C. Pérez de Arce).



Figure 8 PIMA (Portable Infrared Mineral Analyser) at use in the field. Anne Thompson of PetraSciences Inc. was the MAP course instructor in PIMA training sessions conducted for geologists from participating countries (photo by A. Thompson).

Austral area, 24-28°S, 69-69°30' W; 2) an irregular area covering border areas shared by Peru, Chile, and Bolivia, 14-21°S, 66-73°W; and 3) an area covering border areas shared by Argentina and Chile, 31-32°50' S, 69°40'-71°W. The first airborne survey, the Argentina Puna Austral area, was completed in September 1998, with the results distributed to the participating countries and industry partner companies in January 1999. General public release of the data was made on 8 January 2000. The other two airborne geophysical surveys, involving magnetometry/spectrometry studies, are slated to take place in year 2000. These surveys are managed by MAP and funded by a consortium made up of MAP, government, and industry partners. The airborne geophysical surveys are flown to high-quality GSC aeromagnetic and spectrometric standards.

CONCLUSIONS

The Multinational Andean Project is an important international initiative for Canada in terms of scientific exchange and the fostering of enhanced relationships between Canadian and South American national geoscience agencies and mineral exploration companies. MAP will have a long-lasting scientific legacy in the form of geological and metallogenic maps consistent across international boundaries, a multicountry analytical geochemical data base, local petrological sample standards for Andean volcanic rocks, extensive geophysical survey information, and scientific publications. One of the key benefits of MAP cooperative studies is the significant increase in the field and analytical abilities achieved by geoscience personnel from the four participating South American countries. The high level of co-operation

established among the participating countries — Argentina, Bolivia, Chile, Peru, and Canada — provides an excellent model for future international projects.

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