Ignacy Domeyko—an early investigator of Andean geology

I don't want very much—just to be useful to others while I am alive, otherwise life is not worth living.

Ignacy Domeyko

Letter to Onufry Pietraszkiewicz, 1820

There is time for everything when there is a will and God's blessing; and of all the miseries that people complain about in this world, the only one I have not yet experienced is boredom.

Ignacy Domeyko

My Journeys: Memoirs of an Exile, 1962–1963

In 2002, the name of Ignacy Domeyko was listed in UNESCO's list of famous persons. The bicentenary of this famous nineteenth-century scholar and teacher, geologist, mineralogist, and ethnographer was widely celebrated in Chile, Lithuania, Belarus, Poland, France (Grigelis, ed., 2002).

Ten years after his arrival in Chile, Domeyko published an article entitled *Mémoire sur la constitution géologique de Chili* (Annales des Mines, Series 4, Volume 9, 1846), in which he suggested an ongoing tectonic factor forming the Andean Cordilleras:

*Tout annonce que le principal mouvement qui survint à l'époque de la formation des Andes arriva du côté de l'Ouest, c'est-à-dire du côté où une ligne d'escarpements qui marquent le rivage actuel de l'Océan depuis le cap Horn jusqu'aux montagnes Rocheuses, continue à se soulever d'une manière lente et à peine perceptible, au mugissement des bruits souterrains et sous l'influence des tremblements de terre répétés (p. 414).**

This suggestion was far ahead of its time. More than a century later, the theory of plate tectonics confirmed the existence of the Nazca Plate moving eastwards from the Pacific Ocean, fundamentally affecting the geological structure of the Andes (Maksaev and Zentilli, 1999).

Ignacy Domeyko (1802–1889)

Ignacy Domeyko (in Lithuania — Ignotas Domeika; in Chile — Ignacio Domeyko Ancuta; Figure 1) was born on 31 July 1802 into a family of Polish-speaking Lithuanian nobleman on an estate, Niedzwiadka, in the Korelichi district (former Grand Duchy of Lithuania; more recently in Belarus). After attending a Piarists secondary school in Shchuchyn from 1812 to 1816, he entered Vilnius University in 1816 and graduated in 1822 (Wójcik, 1995). From 1819, he was a member of the secret 'Society of Philomaths' in the University, but in November 1823, he was arrested and imprisoned in the Basilian Monastery. In 1824, he was exiled from the city under police supervision for six years, on an estate of his uncle Ignacy in Zapole, Lida district. In 1830–1831, he took part in the so-called November Uprising, but after a defeat near Šiauliai (in Lithuania) in the summer of 1831 he, and other rebels, fled to Prussia. After a year spent in Dresden, Germany, Domeyko, together with his friend, the writer Adam Mickiewicz, went to Paris, where he stayed from 1832 to 1838. First he studied at the Sorbonne, *Collège de France*, and the *Jardin des Plantes*. In 1834, recommended by Léonce Élie de Beaumont, Domeyko became a student at the *École des Mines* and after three years of study he graduated on 1 August 1837 with a diploma in mining engineering. For a few months Domeyko took part in

prospecting for iron ore in Alsace but near the end of 1837 he received a letter from his mineralogy professor Pierre Armand Dufrénoy offering him an invitation to go to Chile to teach mineralogy and chemistry in La Serena Mining School, Coquimbo Province.

On 31 January, 1838, Domeyko left Paris, and, after a voyage of four months across the Atlantic by packet boat from Falmouth in England to Buenos Aires, he crossed Andes by horse and reached Coquimbo on 3 June. Domeyko was contracted to work in Chile for six years but instead he was there for no less than forty-six years. In 1884, he returned to Europe with his sons, Hernan and Kazimierz, travelling to Paris, Rome, Palestine, Cracow, and Vilnius, and spent four years on the estate of his daughter Anna in Zyburtowszczyzna, Grodno District, making tours to relatives and friends and writing his memoirs (Paz Domeyko, 2002). Late in 1888, he returned to Chile. On 23 January 1889, Domeyko passed away in Santiago and was buried by the side of his lovely young Chilean wife Enriqueta Domeyko Sotomayor, who had died on 26 December, 1870, aged only thirty-five.

Domeyko worked at La Serena College (now La Serena University) from 1838 to 1846 as a professor of mineralogy and chemistry, but also as a mining engineer (Domeyko, 1845b). In the years 1839 to 1844 he conducted geological researches in the Andean Cordillera and Atacama Desert every summer season, travelling over 7,000 kilometres, mostly on horseback (Figure 2). In 1844, he travelled to Araukania in southern Chile and described the Araukanian Indians (Mapuches) in his book *Araucania y sus habitantes*, published in Spanish in 1845, later translated into Polish and published in Vilnius in 1860 (Domeyko, 1845a, 1860), and subsequently issued in translations in various countries of South America, as well as in France and Germany.

In 1846, Domeyko was invited to Santiago where he was initially occupied as a University Delegate for the reform of the Chilean state education system. From 1867 to 1883, he was four times elected Rector of the University of Chile in Santiago. In addition, he introduced a network of meteorological observatories in Chile (Ryn, ed., 2002).

Domeyko is generally regarded as the 'father of mining geology' in Chile. He developed knowledge of copper, silver and gold mineralogy, and mining techniques (Domeyko, 1878). He published his results in professional periodicals, mainly in France, Germany, and Chile. In all, he authored around 560 scientific works, and left thousands of pages of diaries, letters, and essays (Domeyko, 1962–1963, 1978, 2002a, 2002b). There are more than four thousand publications about Domeyko (Ryn, ed., 2002). Over 110 terrestrial things—cities, mountains, fossils, minerals, etc. (e.g., *Domeykosaurus chilensis*, the Domeyko fault system, Domeyko's Ridge)—are named in his honour, and there is even the Domeyko asteroid (Motuza, 2002). Both during his lifetime and through to the present, Domeyko is remembered in his native countries and by his schools and universities. His biographers have noted the spirituality of his personality. His activities in Chile and his regular contacts with European scientific centres served as an intellectual bridge between Europe and South America.

Figure 1 Ignacy Domeyko. Portrait, Tygodnik Ilustrowany, No. 186, 1871, 37 [Library of the Lithuanian Academy of Sciences, Vilnius].

* *Everything suggests that the principal movement that has occurred during the formation of the Andes came from West, i.e. from the side where the line of escarpments that marks the present coastline of the [Pacific] Ocean from Cape Horn to the Rocky Mountains is slowly and barely perceptibly rising, with subterranean noises and under the influence of repeated earthquakes.*

Figure 2 Domeyko's travel routes in Chile, 1838–1889 (after Wójcik [1995], 633).

In 1887, Domeyko received an MD *honoris causa* from the Jagiellonian University. He was also a Member of the Academy of Arts and Sciences in Cracow, as well as numerous scientific institutions in America, France, Germany, and Austria. He discovered twenty-seven previously unknown minerals, naming them by famous names: arquerite, algodonite, copiapite, coquimbite, daubreeite, toconalite, chileite, kroehnkite, phillipite, etc. In 1845, one of the new minerals, sent by Domeyko for determination in Europe, was named domeykite (Cu_3As) by the Austrian mineralogist Wilhelm Karl von Haidinger (Koszowska and Wolska, 1988).

Domeyko was undoubtedly a 'Citizen of the World'. Formerly the author of this paper thought he could take a detached view of him and his epoch. However, I had to go deeper into his life and achievements (Grigelis, ed., 2002) and reached the conclusion that Domeyko took his place beside Adam Mickiewicz as one of Lithuania's greatest figures.

Forgotten autobiographical fragments

In his acceptance address upon his election to the Academy of Arts and Sciences in Cracow in 1874, Domeyko described himself briefly as follows:

Domeyko Ignacy ... born in Niedźwiadka near Novogródek in July 1802, Master of Philosophy of Vilnius University, Rector of the University of Chile, and President of the University Council in Santiago, Professor of Mineralogy, Geology and Physics..., Fellow of the Literary Society and the Society of Exact Sciences, Paris, the Societies of Natural Sciences in Mexico, Bogota, Buenos Aires, and Nürnberg, and of the Geographical Society of Berlin [fide Wójcik, 2002].

Several years later, Domeyko sent a more detailed description of his activities to Cracow. The following extracts from his letter state his main achievements and their world-wide significance.

Following my arrival in South America [in 1838], in the first years of my stay there and during the months when I was free from my teaching duties, I travelled to the Cordilleras, many times reaching their watershed and crossing to the other side of the Andes. The samples collected during these expeditions were analyzed by me in my laboratory. I informed my former professors in the École des Mines in Paris—de Beaumont and Dufresnoy—about the results of these studies and, after their death, I communicated with my former fellow student at this school and its present Director, Monsieur Daubrée. They were so kind as to present my reports to the Académie des Sciences in Paris and to publish them in the Annales des Mines, edited by French mining engineers in the years 1842–1877.

It is comprehensible that over a period of so many years it was several times necessary to change and correct the opinions that I first proposed about the very complicated structures of these enormous mountains. The naturalists who had visited Chile before me—Gay, Pöppig and Mayer—were more interested in botany and zoology and less in the mineral kingdom. Darwin recognized only the sea-shore zone of younger formations. Dana and d'Orbigny merely touched on the granitic rocks of Valparaíso. In 1848–1849 Pisis began triangulation of the country from Copiapó to Bio-bio (27°–37° latitude) and worked on a geological map for about twenty years. Due to the lack of cross-sections and detailed data on the relative position of beds, he tended to subdivide the formations into separate hypothetical members, without adequate palaeontological characterization.

As far as my own activities were concerned, I paid particular attention to the more prominent features, distinguishing two main Cordillera ranges within the territory of Chile. In 1845, I first presented my mode of approach to the geology of this country, elaborated during my journey through Chile and published in Annales des Mines in 1846 (Volume 9). In the accompanying map, I marked a boundary between the two mountain chains, i.e. the coastal or western and the eastern Cordilleras of the Andes proper. The determination of this boundary was essential for indicating the places where the main metallic deposits occurred. As far as the relative age of these complicated formations was concerned, I chose (many years later) the only Liassic calcareous–argillaceous member as the geological marker horizon, with its abundant and characteristic fossils of this age, thereby enabling me to subdivide the whole sequence of layered rocks into post- and pre-Liassic series.

In addition, my geological expeditions allowed me to become acquainted with the nature of the country. The considerable diversity of climate and abundance of mineral resources renders it unique in the world. During my repeated journeys in Chile, several hundreds miles long—from the Atacama Desert to Osorno, and from the sea to the summits of Andes—I have observed and distinguished four completely different zones and this subdivision has been accepted in Chilean physical geography. In each zone, a strict relation between the outward form (relief) and the internal geological nature of the rocks and strata forming them may be observed. I endeavoured to explain this in my paper on the theme proposed by the Geological Society in Paris: Faire ressortir les rapports qui existent entre le relief du sol et la constitution géologique. It was published in a collective volume of papers on the physical geology of Chile, sent by the Faculty of Natural Sciences of our University in 1876 to the International Congress of Geographical Sciences in Paris [Estudios geográficos sobre Chile 1875, Santiago, p. 30]. But my work and attention were chiefly focused on the study of local minerals, for which the main method I used was their chemical analyses. The almost complete lack of well-crystallized minerals in the Chilean Cordillera meant that I could make little use of the goniometric method. The mineralogy of this country is predominantly the min-

eralogy of amorphous bodies. Therefore, in many respects the most important feature, both industrially and scientifically, is not their form but their chemical composition. But the latter is commonly variable, necessitating the application of analytical methods. This time-consuming procedure is recompensed by learning the natural associations of various metals and metalloids, their isomorphisms, and their mutual affinities. My first descriptions and analyses of newer minerals were published in the *Berzelius Jahres-Berichte*, the *Comptes rendus des séances de l'Académie de Sciences in Paris*, as well as in *Annales des mines in the years 1845–1850*. Every few years my later discoveries appeared in the *Annales des mines* and in the *Yearbook of the University of Santiago*. In 1860, in the second edition of my monograph on mineralogy, I presented a full list of the more important minerals occurring in Chile and neighbouring countries. In 1867, 1871, 1874, 1876, and in 1878 I published six Appendices to this *Reino Mineral [Mineral Kingdom]*, in which I described numerous new South American minerals, their analyses, and the localities where they occur [fide Wójcik, 2002].

The foregoing text is part of a letter sent by Domeyko to Crawford in 1878 with his treatise *A View of the Chilean Cordillera and Metalliferous Deposits Contained in their Subsurface*. Consequently, it does not mention the author's other important contributions, including his textbooks on the assaying of ores, which were republished at the beginning of twentieth century.

A view at the Chilean Cordilleras and metalliferous deposits contained in their sub-surface**

[Selected sections, translated by Irena Mirvienė and Mudis Šalkauskas, Vilnius (mudis@ktl.mii.lt)]

Domeyko's understanding of the Maritime Cordillera and the structure and tectonics of the Andes proper came gradually, and his several publications in different years, starting with 1846, appeared in France in *Annales des mines*, in Chile in *Annales de la Universidad* and in his manual *Mineralogia* (1860), in Germany in *Berzelius Jahres-Bericht*, in French, Spanish and German, respectively. The synopsis of the geological structure of the Chilean Cordilleras was published in Polish by Domeyko in 1878 (Figure 3). However, this edition was based on his previous long-term work, as he mentioned in Footnote**. The selected sections from Domeyko's paper have been

Figure 3 Title page of Ignacy Domeyko, *A view of the Chilean Cordilleras and metalliferous deposits contained in their sub-surface*, with author's inscription [M. Mažvydas State Library, Vilnius]

chosen to exemplify Domeyko's ideas and discoveries, set out in the following chapters: the Maritime Cordillera, the Cordillera of the Andes proper, and the belts of metalliferous deposits in Chile. The translation is made directly from Polish to English and follows the text as exactly as possible; original page numbering is given in parentheses, and the original footnote numbers are reproduced exactly.

Structure of the Maritime Cordillera or the so-called Cordillera de la Costa

[14] *The Maritime Cordillera predominantly consists of four different formations, namely:*

- A. *Crystalline Rocks (plutonic): massive non-layered, partly granitic or of dense porphyritic structure; schistose in the southern maritime areas. Generally they represent eruptive rising rocks.*
- B. *Chains of some ancient strata resting in places upon them, presumably from some Transition Period, the age of which cannot be determined owing to the complete absence of fossils.*
- C. *Those in lowlands and depressions in the previous formations, namely in places where, during the Tertiary Period, they were formed in larger or smaller basins. Tertiary schistose deposits and limestones can be seen in the northern area and in the southern areas occur silty sandstones and brown coals.*
- D. *Late or Recent levée alluvial deposits with grains of gold, fluvial and lake deposits, salt, saltpetre, guano, and dune deposits.*

A. Plutonic rocks

The main part of the Maritime Cordillera is granite, commonly consisting of two types of feldspar (orthoclase and oligoclase), quartz, mica, and various iron minerals with an admixture of the following minerals: green epidotic tourmaline, garnets in some places, beryl, and rutile. Mica is lacking in the granite; one of the granite's feldspars, namely the white type, decomposes easily as compared to the yellowish one or reddish lamellar orthoclase. The whole granite mass easily disintegrates in situ to yield gravel and coarse fragments. The more solid granodiorite, which passes through it, consists chiefly of amphibolites and white feldspar in large dikes, veins or large irregular masses, which are better able to resist prolonged exposure to the atmosphere; and only at the corners and edges—where they are more exposed to the atmosphere—are they rounded and decayed to yield, not gravel and coarse sand, but coarser, irregularly shaped tabular bodies. It seems that the diorite veins stood out for a long time like walls, as they are not protected by weathered and degraded granite. Subsequently they spread and decomposed to form large tabular masses that have gradually become rounded under exposure to the atmosphere in situ and were then buried by gravel and sand washed down from above—apparently being fluvial material, carried from afar by powerful torrents.

The ordinary granite very frequently becomes pegmatite in this part of Cordillera. The quantity of contained quartz often decreases as well, and the rock becomes a partly compact or granular feldspathic mass, or white or yellow china-clay (kaolin).

An equally large area in the northern part is occupied by a diorite mass, consisting of white feldspar (oligoclase, albite) and a black or dark, greenish silicate of compact or fibrous structure, which is considered by mineralogists to be made up of amphiboles. However, up to now over the whole length of the Cordillera I have failed to find any crystals of such minerals, from the form of which it should be possible to determine the kind to which it belongs. Owing to the presence of white bole and the variable ratio in which iron, calcium, etc., are present, chemical

** Szczegółowy opis geologicznego składu Kordyliery Nadmorskiej i Andów ogłosiłem pierwszy raz w *Annales des Mines*, 1848. Paris, 4me serie, Tom IX, w dwóch rozprawach: (1) *Mémoire sur la constitution géologique du Chili* pp. 365–540; (2) *Recherches sur la géologie du Chili et particulièrement: (i) sur le terrain des porphyres stratifiés dans les Cordillères; (ii) sur le rapport qui existe entre les filons métallifères et les terrains du système des Andes*.

analysis provides no way of determining the precise atomic composition. However, from the proportion of silica it contains, it more closely resembles the composition of amphiboles than that of pyroxenes. The white feldspar practically never appears in crystalline form in this rock, and only very occasionally in veins, which, when broken, allowed me to observe a small crystal of the feldspar, though far from ideal, from the Tertiary Period. It is a sodium–calcium feldspar, similar in composition to oligoclase, and in some variants it is similar to albite.

The diorite rock generally forms the higher peaks, rising above the others in the Maritime Cordillera. As concerns their composition, size, and the relative quantity in which the grains of feldspar and amphiboles are found, they are so variable that they constitute a large proportion of the rocks, which appear to be completely different. A coarse-grained rock is rarely encountered. More frequently, it is a fine-grained one, which transforms into a blackish or greenish rock, monolithic in appearance, in which amphiboles and feldspars are so mingled that they cannot be distinguished even with a microscope, and the transformation from diorite granites into the latter rocks is typically gradual and hardly discernible¹. Various black and green masses of porphyry are seen in which white feldspar is scattered as amorphous small crystals (green porphyry), in grey-green solid or fine-grained masses. These are innumerable and it is difficult to characterize rocks of this kind, which transform into dark, uniform diorite masses of granitic texture, belonging to the so-called greenstone (Grünstein).

When compared with the previous rocks, in the Maritime Cordillera, syenites—which consist of lamellar orthoclase, yellow or reddish quartz and green or black amphibole—are less common. At some sites on the coast, the coarse-grained granitic rock can be seen with black lamellar silicates, somewhat similar in chemical composition to pyroxene or hypersthene, while the feldspar resembles labradorite.

It should be added that, in general, as concerns the external characters such as the variety of unfoliated plutonic rocks [such as] granite, grading into uniform porphyry, it was common in the Cordillera to find a great variety of different kinds of rocks on a moderately high hill, so that if someone found them in a museum they would not think that they belonged to the same piece and would separate them into different classes and kinds.

Granite schists in the Maritime Cordillera, namely gneiss, mica schist, or talc, and 'filady' (meaning ancient schistose silt) here and there contain disseminated andalusite (schistes maclifères) and are closely connected with the plutonic, i.e. granitic, rocks. These crystalline schists only occur rarely in two northern zones that are rich in diorites, greenstones and metallic veins, in contrast to the western slopes of the Maritime Cordillera in the south, beginning from the Maule River, in the whole of La Araucania in Valdivia and Llanquihue Provinces—that is in that part of the zone of the Cordillera where no metallic deposits have been found with the exception of [some] sands, poor in gold. It should also be noted that the crystalline schists appear only on the western slopes from the coastal region, lying on the granite, and they gradually give way to granite rocks. Their stratification always depends on the flakes of mica or talc which are packed uniformly. ...

The composition of the Cordillera of the Andes proper

[22] There is no way of recognizing and determining the fundamental difference in nature of the two main ranges of the Chilean Cordillera from their appearance or broad outline and configuration, nor can one judge with certainty where they are contiguous.

Although the Andes are three or four times higher than the Maritime Cordillera, there are plenty of individual mountains as high as the southern Andes in the northern part of the Maritime Cordillera (Figure 4). In many places the traveller crossing both of the Cordilleras from west to east will not even notice when he finds himself in the uplands that are considered to be the Andes proper by naturalists and local inhabitants. The crossing of the Cordilleras, rising to four to five thousand metres above sea level, does not make a huge impression on the traveller when he slowly and gradually approaches them after many days of journey.

The difference between the two ranges can only be sought in their geological structure. From this point of view, the Maritime Cordillera does not seem to present problems with its structure, whereas the Andes, by contrast, are huge monuments to earthquakes that have occurred repeatedly in various epochs. The stratified rocks belonging to the different formations are not arranged clearly over wide areas, one under the other, in distinct layers such that their relative bedding, or stratification, can be observed. They are cut, fractured, and intersected by various eruptive masses, which have moved and separated them. The rocks do not form interconnected links [of a chain], and do not

Figure 4 Schematic section of the Cordilleras from Domeyko's A view of the Chilean Cordilleras ... (1878, p. 170). Kordyljera Nadmorska = The Maritime Cordillera; Andy = Andes; Równina Środkowa = Central Plain; Chiloe Wyspy = Chiloe Peninsula; Zatoka Reloncavi = Reloncavi Bay; poziom morza = sea level. Scale at left shows altitude in metres. Sections across the Andes are given for 33°30', 35°30', and 41°20' degrees south, respectively.

¹ Lack of instruments and microscopes with high resolving power, lack of specialists here able to cut the rock into thin transparent sections, as well as lack of time and a slight amblyopia, gave me no way of performing microscopic studies of the rocks of this type.

preserve their characteristic features. Metamorphosed or problematic rocks dominate. ...

I The altered or metamorphosed rocks²

- [27] With slight changes in mineralogical features, these rocks are found through the whole belt of the lower Andes, in contact with the plutonic rocks belonging to the Maritime Cordillera, as well as in higher zones in which the eruptive crystalline rocks crop out along the surface of the Andes.

The so-called variegated porphyries (*parfidos abigarrados*) dominate in these altered rocks. They split into strata a few feet in thickness, or more often into thinner ones, hardly as thick as one third of an inch. ...

Conglomerates of various colours, mainly breccias and colourful brocatello [variegated marble], are below the porphyries; very rarely there are true pudding stones. The same multi-coloured porphyries produce their own binding material with which they are stratified, forming an argillaceous hardened mass. Moulded parts of these conglomerates are of various types: some compact, others of porphyritic structures, never quartz, commonly crystalline. However, rounded porphyries, deposited in and bound together by clayey material, can also be observed among them. ...

III Eruptive, unbedded, uplifted rocks

- [33] Here the rising plutonic masses uplifted the sheet-like pre-Andes formations and gave them a particular form, which should be distinguished from the eruptive, later, trachytic and volcanic rocks, which have come to the surface in the highest parts of the Andes in the most recent earthquakes and have formed their present shape and outline.

The plutonic rocks generally lack granite and coarse-grained, easily decomposing, pegmatites as well as granite/schist rocks, gneisses, and mica schist, which mainly enter into the composition of the Maritime Cordillera. Only diorite masses, and accompanying greenish, homogeneous or porphyritic mixtures of white feldspar and amphibole (*Grünstein*) which seem to be the main uplifted rock in the Andes as well as in the western range of the Cordillera—make their appearance (*roches de soulèvement*).

It was noticed that the plutonic rocks, as well as granite/schist rocks, gneiss and mica schist of the Andes, lack granite and coarse-grained and easily decomposing pegmatite, which mainly enter into the composition of the Maritime Cordillera.

Diorite and accompanying masses of greenish, monolithic or porphyritic rock, being mixtures of feldspar and amphibole (*Grünstein*), which in the Andes are similar to the western belt of the Cordillera, seem to be the main uplifted rock (*roche de soulèvement*).

In places, syenites consisting of red orthoclase, green or black amphibole and quartz, and much more rarely labradorite granites, with pyroxene—the latter being somewhat similar to hypersthene—crop out at the surface.

It is noteworthy that granitic rocks or diorites are not found on the [main] ridge of the Andes: they do not form their peaks.

From the six places where I crossed the Andes—Cordillera Come-Caballo lying opposite Copiapó,³ Cordillera de la Laguna opposite Coquimbo,⁴ La Cumbre on the way to Uspallata,⁵ Las Dames,⁶ La Puerta del Yeso near Descabezado,⁷ and Pichachera near Antuco⁸—only at the top of the Cordillera de la Laguna did I find a granite rock consisting of red and white feldspar and

small quantity of quartz and amphibole, splitting into vertical prisms, similar in appearance to trachyte. ... According to [the French geologist Aimé] Pissis [who spent most of his career in South America], even the highest Cordillera in the Andes, Aconcagua, is neither granite nor volcanic. Trachytic cupolas and cones dominate the whole of the eastern Andes. ...

- [39] The western boundary of the Andes in the Atacama Desert has not yet been identified. It is only known that Mount Caracoles, situated between the 23rd and 24th degrees of latitude, consists wholly of stratified limestone and contains Jurassic fossils: to the west they are adjacent to the granitic rocks of the Maritime Cordillera.

Travelling southwards from this point, following the Jurassic outcrop, we find the intersecting lines near the places where Philippi and Sund found large numbers of Liassic remains: at Profeta, Sandon, Juncal, Encantada, and as far as Floryda. The boundary line through the Atacama Desert continues parallel to the coast, at a distance of about one degree of longitude. Interrupted Jurassic limestones, covered in many places by trachyte resting on metamorphic porphyries and red marls (Philippi) start at Floryda and reach Tres Puntas; and here begins their zone, better known and rich in metalliferous deposits.

The town of Copiapo, situated in the deep valley sheltered from the south by the diorite mountains of the Maritime Cordillera has a high range of stratified and altered rocks to the north, situated at the edge of the formation. A couple of miles to the east on the southwest slope of Mount Ladrillos is the junction of the lower diorite mass with the Lower Lias strata, which is elevated by the former.

From Mount Ladrillos it is easier to observe the line of contact to the east. It may be seen where it intersects the valley of the River Copiapo and, undisturbed, it reaches Chanarcillo, famous for its silver mines. Here, at the foot of Jurassic limestones in Juan Godoy village, a granitic rock crops out at the surface. ...

- [40] The boundary between the two Cordilleras stretches southwards to 50 to 60 miles from Chanarcillo, as far as Agua Amarga. However, the line is hidden for the whole route under a wide, elongated sandy plain, which here separates the eastern Jurassic range from the unbedded crystalline masses of the western Cordillera. ...

From this site, the contact line turns again towards the Andes, traverses the crosswise running valley of the River Conquimto not far from Marquieza, and then turns again towards the south. Well-stratified limestone with Jurassic fossils becomes less common and latter disappears and instead varicoloured porphyries and altered rocks of various kinds, with grey and red sandstones, predominate. ...

IV The belts in which the metalliferous deposits in Chile are situated, and the places they occupy in the composition of the Maritime Cordillera and the Andes

In this part of his paper, Domeyko gave a summary and interpretation of the field and laboratory data relating to Chile's numerous metalliferous deposits: how they originated, and how their composition reveals particular regularities. This was a major part of his scientific work in his adopted country, where he was often the first geologist to visit a region. Among his wide range of interests, his principal themes were mineralogy, ore geology, and metallogeny, in which fields he achieved major results. Later investigations have confirmed

² Daję szczegółowszy opis tych porfyrów w rozprawie ogłoszonej w, *Annales des Mines*, p. n. "Recherches sur la géologie du Chili, etc.", którą powyżej przytoczyłem.

³ *Annales des mines*, 1846; *Recherches géologiques*, p. 402.

⁴ *Recherches géologiques*, p. 529.

⁵ *Podróż z Paryża do Chili*.

⁶ *Excursion géologica a las Cordilleras de San Fernando*; *Anales de la Universidad*, 1861, p. 22.

⁷ *Viaje a la Cordillera de Talca i Chillan*; *Anales de la Universidad*, en 1848, p. 12.

⁸ *Mémoire sur la composition géologique du Chili á la latitude de Concepción depuis la baie de Talcahuano jusqu'au sommet de Pichachen*, comprenant le volcan Antuco, par J. Domeyko; *Annales des mines*, 4 Serie, Tom XIV, pp. 63–186.

Figure 5 The principal metallogenic belts of north Chile, observed by Ignacy Domeyko, and the position of the largest copper and gold porphyry deposits, after Motuza (2002, p. 181).

the picture of Chilean metallogeny described by Domeyko (Figure 5). According to recent scientific opinion (Maksaev and Zentilli, 1999; Oyarzun, 2000; *fide* Motuza, 2002 and 2003), "Domeyko determined the main regularities in Chilean metallogeny, which were later confirmed, i.e. metallogenic zonation, with a belt of distribution of various metals and ore deposits, related to magmatism and the tectonic control of the deposits, along with their distribution along tectonic fault zones (the systems of the Atacama and Domeyko faults). Domeyko ... also expressed the idea of [tectonic] pressure coming from the west. This intuitive supposition was proved after a hundred of years by the modern theory of plate tectonics". Thus Domeyko's ideas on Chilean metallogeny as being determined by tectonic control and endogenous factors, can properly be considered 'classical'.

[68] It seems to be generally accepted by geologists that the best and most numerous metallic deposits are found where rocks and formations of different origin and composition come together, or near such places, most frequently where eruptive, crystalline, plutonic, or elevating rocks, meet ancient, inclined, sedimentary strata.

The least popular opinion is that the kinds of metallic deposits depend on the kind of rocks where they are found and on the geological epoch during which they were formed.

The boundary line between the Andes and the Maritime Cordillera [see Figure 4], which I endeavoured to define above,

as far as the imperfect state of knowledge of geology of this country allowed me, provides a basis for evaluating the extent to which this practical generalization is confirmed by the composition of the Chilean mountains, and to determine the role of the major deposits in their composition.

The innumerable Chilean mines for copper, silver, tin, mercury, etc., are widely known hitherto from their disposition and nature and may be classified according to their three main belts:

A) The first, central, belt of metalliferous deposits extends beyond the joining lines of the other two different formations, near it to the east. It is mainly formed of stratified Jurassic limestones. The veins are abundant in chlorides, chloride-bromide ores, native silver, and amalgam.

B) The second belt is situated wholly within the Andes and [lies] to the east of the previous belt [A]. It lies between the belt extending beyond the contact line and the highest line of the Andes watershed.

C) The third belt of mines in the northern parts of the country is far removed from the Andes ridge. However, the further it shifts to the east, the closer it approaches them. So between 35° and 36° of latitude it almost completely disappears at their peaks. Metamorphic rocks, porphyries; porphyry breccias, and others—most probably red sandstone—are dominant. The minerals commonly contain arsenic, antimony, and tin; and zinc, and iron sulphides are abundant. The contained copper is almost invariably admixed with silver in relatively low quantity. The deposits are more or less siliceous or clayey (argillaceous). The third band occupies nearly the whole of the Maritime Cordillera as far as 35°–36° of latitude. To the east, it borders the boundary line, and to the west, it borders the sea. The metallic deposits there are abundant in copper; their ores are pure and are almost free from both arsenic and antimony; and most commonly they contain neither silver, zinc, nor tin. Gold appears throughout the band, though rarely, in veins and alluvial deposits.

Diorite rocks and the overlying greenstone of compact or porphyritic texture, with eutitic quartz porphyries in places, enter into the composition of the Cordillera and seem to be the richest in metallic veins.

As mentioned above, these are the rocks that in many places have uplifted the stratified formations of the Andes, which suggests that where this occurs they have pierced through them repeatedly. For instance, we have it in the mines at San Francisco del Volcans, at the confluence of the River del Volcano with the River Maipo, where the deposits present in these diorite masses appear to be of the same nature as they are in the Maritime band.

The central part of the Andes, which is several miles wide, is the poorest in metalliferous deposits or is lacking in them completely. It is situated between the second belt and the highest mountains of the [Maritime] Cordillera in the northern provinces and forms the whole of the trachyte formation in the southern provinces.

Domeyko's text continues with detailed descriptions (pp. 71–113) of the rich silver, copper, and gold deposits common in the Central Andian (Caracoles, Floryda, Tres Puntas, Chanarcillo, Arqueros), Eastern Andian (Los Bordos, La Rosilla, San Antonio del Potrero Grande, Carriso, Tunas, Catemo), and Western Andean (Chanaral, Carrizal, Puntadel Sobre, Ojanco, San Juan, Tamaya, etc.) metallogenic belts. However, some of the richest mines that yielded remarkable Chilean minerals in the past are already exploited, deserted, and fallen into disrepair.