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Historical memory of the geology of Antioquia: Emil Grosse and The Carboniferous Tertiary of Antioquia

Memoria histórica de la geología antioqueña: Emil Grosse y El Terciario Carbonífero de Antioquia

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ABSTRACT

The Carboniferous Tertiary of Antioquia (TCA), published by Dr. Jakob Emil Grosse in 1926, is one of the most influential scientific results of the Ordinance 16 of 1918 of the Honorable Departmental Assembly of Antioquia. The work began with the main objective of quantifying the coal reserves of Antioquia, and showing their surface extension on a scale of 1:50 000, in a region that includes the Arma river to the Puente de Occidente and from the western side of the Cauca River to the Romeral lineament and the plains of Ovejas. As a result, extensive work comprising petrological, structural, and economic geology studies was published in a manuscript published in Spanish and German, plus four attached maps, including coal, gold, silver, kaolin, and carbonate mines, among others. In the present work, the four TCA maps were digitized at a scale of 1:50 000 with Bessel 1841 datum and created a unified file in .kml format, which can be used directly in field trips, via Google Earth on cell phones, tablets, or computers. The metadata associates the information in the TCA with the Servicio Geológico Colombiano for the year 2015. In addition, 480 thin sections were scanned, which were donated by Dr. Grosse to the Escuela Nacional de Minas and today are in the Museum of Geosciences of the Faculty of Mines of the Universidad Nacional de Colombia. The geospatial information contained in each thin section was interpreted and georeferenced, obtaining, as a result, a list with north and west geographic coordinates, in degrees, minutes, and seconds. This unpublished information is available in the supplementary material of this article. Finally, nine field trips were made to the places referenced in 23 photographs of the TCA between 1920 and 1923 to take their current equivalent and thus carry out a multi-temporal analysis of the TCA.

Keywords: Amagá Formation, geological heritage, museum of geosciences, Colombia.

RESUMEN

El Terciario Carbonífero de Antioquia (TCA), publicado por el Dr. Jakob Emil Grosse en 1926, es el resultado geocientífico más influyente de la Ordenanza 16 de 1918, de la Honorable Asamblea Departamental de Antioquia. El trabajo se comenzó con el objetivo principal de cuantificar las reservas de carbón del departamento y mostrar su extensión superficial en un mapa en escala 1:50 000, para la región comprendida desde el río Arma hasta el puente de Occidente y desde la margen oriental del río Cauca hasta la cuchilla del Romeral y los llanos de Ovejas. Como resultado, se publicó una extensa obra que comprende estudios petrologógicos, estructurales y de geología económica, en un manuscrito publicado en español y alemán, más cuatro mapas adjuntos, en los cuales, además del carbón, también se cartografiaron las minas de oro, plata, caolín, carbonatos, entre otros. En el presente trabajo, se digitalizaron los cuatro mapas del TCA en escala 1:50 000, con datum Bessel 1841, y se creó un archivo unificado en formato .kml, el cual puede ser usado directamente en campo, vía Google Earth, mediante celular, tablet o computador, y cuyos metadatos asocian la información del TCA con su equivalente del Servicio Geológico Colombiano del año 2015. Además, se escanearon 480 secciones delgadas, que pertenecen a las colecciones patrimoniales del Museo de Geociencias de la Facultad de Minas, de la Universidad Nacional de Colombia. La información geoespacial contenida en cada lámina se interpretó y se georreferenció, obteniendo como resultado un listado con coordenadas geográficas norte y oeste, en grados, minutos y segundos, información inédita y disponible en el material suplementario del presente artículo. Finalmente, se realizaron 9 salidas de campo a los lugares referenciados en 23 fotografías del TCA entre 1920 y 1923, para registrar su equivalente actual y de este modo realizar un análisis multi-temporal del TCA.

Palabras clave: Formación Amagá, patrimonio geológico, museo de geociencias, Colombia.

1. INTRODUCTION

In 1918, the Honorable Departmental Assembly of Antioquia established that the governor's office would have the geographical and geological charts and maps of the department drawn up and published, per Ordinance No. 16 of April 6, 1918, for which a board called the Junta del Mapa de Antioquia (Zuluaga et al., 2005) was created. As a consequence of this ordinance, and by recommendation of the Antioquia Railroad, the Escuela Nacional de Minas, the mining company El Zancudo and some private individuals, Dr. Robert Scheibe, professor at the Technical School of Charlottenburg, was asked to lead the project. Among several difficulties, Dr. Scheibe listed that there was a lack of topographic material and scientific base material, and the problem of the mountainous configuration of the terrain, with inaccessible virgin forest areas, to carry out the requested assignment effectively.

Thus, on the recommendation of Dr. Scheibe and Dr. Juan de la Cruz Posada, professor at the Escuela Nacional de Minas in Medellín at that time (Posada, 1936), Dr. Jakob Emil Grosse, a student of Professor Scheibe in Charlottenburg (Germany), was hired to quantify the coal reserves and show their surface extent on a 1:50 000 scale plan, mainly for the Antioquia Railway project. In this way, Dr. Grosse produced a classic book of

Antioquian geology, *The Carboniferous Tertiary of Antioquia* (TCA) (Grosse, 1926), with four associated maps at 1:50 000 scale (Figure 1), for the region between the Arma River and the West Bridge, from the eastern bank of the Cauca River to the Romeral cleaver and the Ovejas plains.

Few studies of this type were carried out prior to the TCA in the carboniferous zone of Antioquia. Nevertheless, there are some geological records on the western foothills of the Central Cordillera. For example, in 1831, the Frenchman Boussingault contributed to understanding the Heliconia salt flats. Likewise, around 1834 and 1860, the Germans Reinhold and Degenhardt studied the regions of Titiribí, Amagá, and Heliconia, and the rector of the Escuela Nacional de Minas at that time, Tulio Ospina, before he died in Panama in 1921, wrote one of the first reviews on Colombian geology (Grosse, 1926). These works contributed significantly to the knowledge of the geology of that region, although there was still a lack of detailed topographic, geological, and structural geological information. In turn, Dr. Robert Scheibe made in 1919 a first draft with geological information of the area, which served as a guide to the map made later by Dr. Grosse (Castro, 2018), although the information was not published due to his death in early 1923 in Bogotá.

Thus, in two years in the field and with one assistant, three laborers, three saddle mules, and five pack mules, Dr. Grosse

faced the task of the Honorable Departmental Assembly. As a final result, the coal reserves were quantified and the mines of gold, silver, kaolin, carbonates and other industrial minerals were mapped. From this work, 480 rock samples and thin sections of rocks are kept in the Faculty of Mines of the Universidad Nacional de Colombia, Medellín, which are currently part of the Faculty Petrographic Collection of the Museum of Geosciences.

Since then, Dr. Grosse's geological collection has had to face the passage of time, with various periods of affectation that reflect the history of the collections of the Faculty of Mines. The present work aims to update the information of the geological and geo-spatial sampler of the four maps, thin sections, and photographic records of the TCA, showing it in an unpublished and open access way utilizing the supplementary material associated with the manuscript.

2. METHODS

2.1. Digitization of the TCA maps

The cartographic base of the TCA is composed of four maps at a scale of 1:50 000 (Figure 1a), which cover the central zone of plates 130, 146, and 166 (at a scale of 1:100 000) of the Instituto Geográfico Agustín Codazzi (IGAC, 2004, 2005a, 2005b). The legend located on map 4 of the TCA does not specify the coordinate system used and only refers to the fact that "Dr. Emil Grosse and Ing. Tulio Arbeláez G. have made a topographic base of the map (Grosse, 1926)". In addition, the company where the maps were produced and printed is named: "Berliner Lithogr. Institut. Julius Mosen, Berlin W35, Posdamersir 110 engraving and printing". Taking into account the above, the Bessel projection (1841), which was widely used in the late 19th and early 20th century, was used for digitizing these maps. In the process of digitalization and transformation of datums, it was observed that, for the World Geodetic System (WGS 84) projection system, the polygons in ArcGIS with Bessel 1841 datum present an offset of 37 km to the E and an areal decrease of approximately 45-50%, specifically for the central zone of Antioquia. Subsequently, the files generated in .shp format were transformed to .kml format to visualize the layers in Google Earth. At the same time, to corroborate that the digitized information effectively coincided with the relief of the area, the

geomorphology of the Cauca river was used, which presents different meanders for the TCA area, facilitating a refinement of the transformed version of the unified map. As a result, from the four initial 1:50 000 scale maps with Bessel 1841 datum of the TCA, a generalized map was created in .kml format (Figure 1b; Supplementary Material 1), which can be used directly in the field, via Google Earth, through cell phone, tablet or computer. To complement the digitization of the generalized map of the TCA, we proceeded to elaborate its current equivalent, based on the Geological Map of Antioquia (González, 1999), its explanatory memory (González, 2001), and the geology and metadata of the Geological Map of Colombia (Gómez et al., 2015). The extracted polygon was also generated in .kml format (supplementary material 2).

2.2. Cataloguing, transcription and georeferencing of TCA thin sections

The Museum of Geosciences of the Faculty of Mines of the Universidad Nacional de Colombia, Medellín, contains part of the hand samples and thin sections of the TCA. In the present research project, the thin sections were specifically cataloged and transcribed. The TCA rock flakes collection comprises 480 thin sections, of which 456 were analyzed because the remaining 24 flakes were in poor condition. The plates were produced by the German company Voigt & Hochgesang of Göttingen, and contain information from three different inventories (Figures 2a and 2b): the first one associated with Emil Grosse's personal catalogue, located at the top right of each plate; a second inventory copied in red, at the top and bottom of each plate, possibly associated with an inventory of the Escuela Nacional de Minas; and an inventory corresponding to the Universidad Nacional de Colombia, with the numbering located at the front of each plate (Figure 2b). In addition to the inventories, the plates contain Grosse's lithological classification, located at the top of the slide of each specimen, and the description of the location, located at the bottom of each thin section. Subsequently, the location of each slide was interpreted to associate them with IGAC plates 130, 146, and 166 and to generate the current coordinates in the WGS 84 system. As a result, an updated layer of sampling points was obtained for each specimen collected by Grosse in the TCA, available in .kml format and associated with supplementary material 3 of this paper.

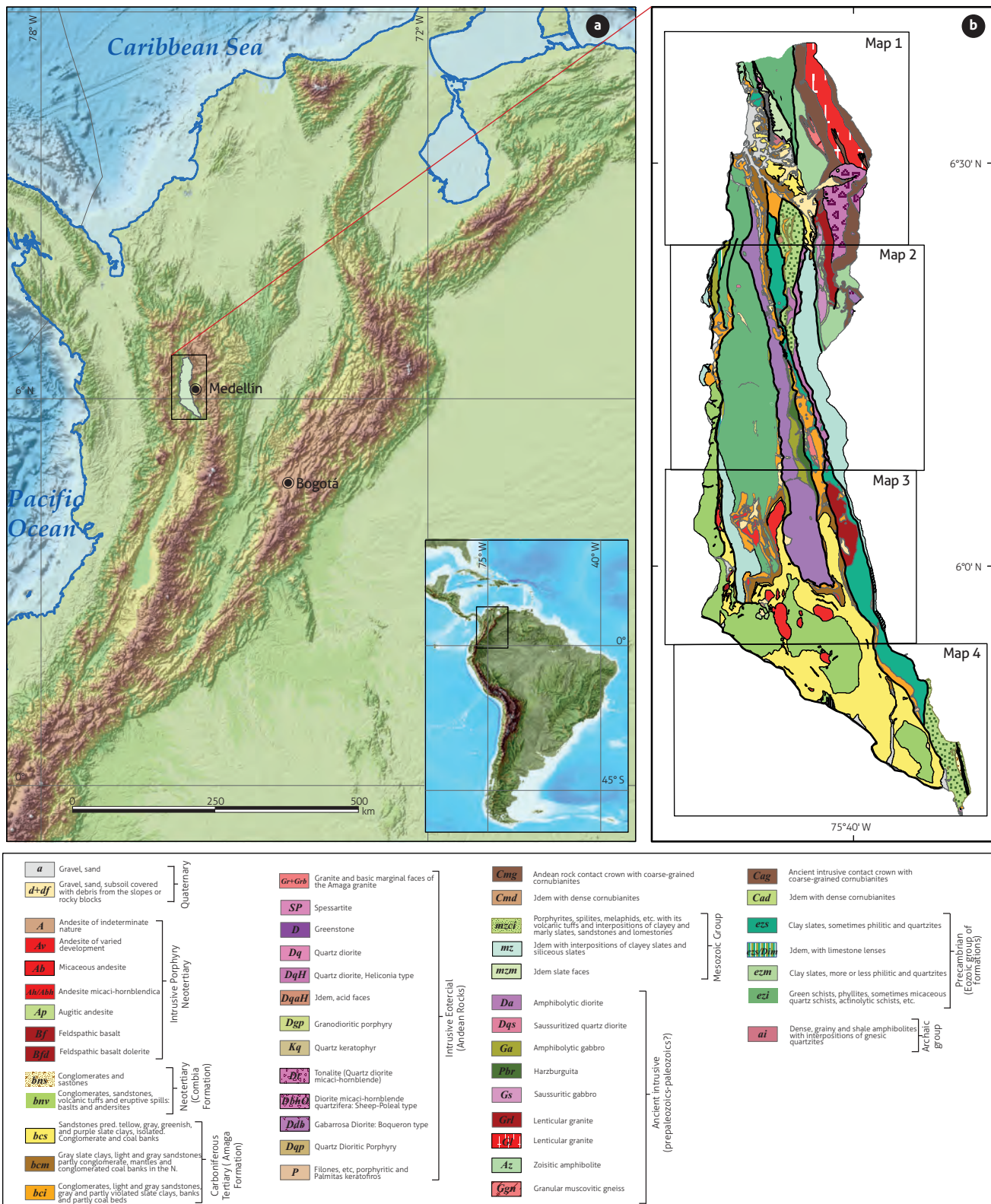


Figure 1. a) General tectonic framework and configuration of the four TCA maps; b) Digitized geological map of the TCA (Grosse, 1926) in the WGS 84 system (Supplementary Material 1)

2.3. Fieldwork and multi-temporal analysis of TCA images

As a complement to the cartographic and petrographic work, we took nine field trips to the referenced locations of 23 photographs recorded by Dr. Grosse in the TCA between 1920 and 1922 to show geoforms, lithologies, and overthrusts (fault zones for Grosse). To georeference them, the location des-

cribed in the legends of the samples was interpreted, and their respective north and west coordinates in the WGS 84 system were generated. To corroborate that the information was reliable, the points were refined in the field. A current photographic record was taken of the landscape images reported in the TCA to show some significant changes in the landscape over a century.

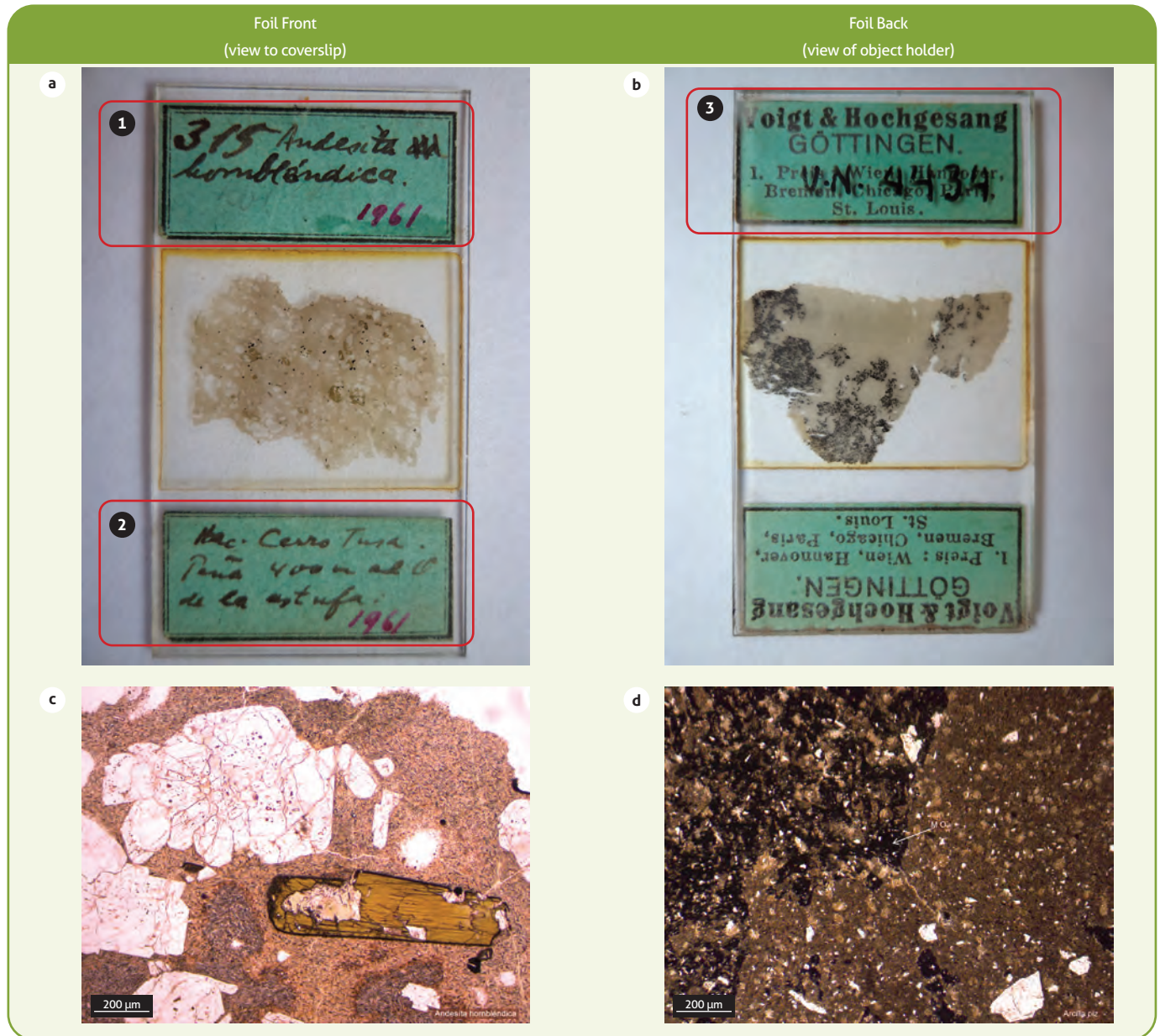


Figure 2. a) Front part of an original thin section specimen from the TCA with 1) Grosse's numbering, lithological classification of the specimen, and numbering of the Escuela Nacional de Minas; 2) Location of the specimen; b) Front part of the thin section with the name of the German factory Voigt & Hochgesang, Göttingen and 3) Catalogue of the Universidad Nacional de Colombia; c and d) are photomicrographs of the thin section in a and b, classified as hornblende andesite, located in Cerro Tusa, and a clay (arcillolite) with organic matter from the Amagá Formation, respectively.

3. RESULTS AND DISCUSSION

3.1. Map of the TCA, a current look at a classic work of cartography

The TCA maps have been, since their production, a classic work of geological reading and bibliographic analysis for the western zone of influence of the Central Cordillera, involving key lithostratigraphic units for the understanding of pre- and post-Andean evolution such as the Cajamarca Complex, the Quebradagrande Complex, and the Combia Formation, among others (c.f. Blanco-Quintero et al., 2014; Maya and González, 1995; Weber et al., 2020). Furthermore, this work also has relevance in the tectonic framework of the area because the work details in detail the Cauca-Romeral fault system, where Grosse approaches with fault mapping and satellite systems, named at the time as *overthrust*, from the German word *Überschiebung*, where "Über" means "over" (e.g., Romeral, San Jerónimo, Cauca E, etc.), mapped simultaneously with the topographic survey, and since then they have been the basis for the tectonic understanding of the area in several works of geodynamics and terrain (c.f. Cediel et al., 2003; Etayo-Serna et al., 1983; Restrepo and Toussaint, 2020; Toussaint and Restrepo, 2020).

On the other hand, one of the mining-economic implications was the mapping of small-scale *pits* and *pits* of metallic and non-metallic projects, such as gold, silver, kaolin, carbonates, among others. These later had a revolution in terms of exploration and mining in the middle belt of Cauca (Sillitoe, 2008), specifically in the polymetallic Au-Ag-Cu deposits, such as Buriticá, Cerro Vetas, La Mina and Nuevo Chaquiro, among others (Bartos et al., 2017; Lesage et al., 2013). Thus, since 1921, where coal was the focus of the TCA because of its strategic nature, the TCA maps became the geological basis par excellence for the lithological, structural, and mining understanding of the area.

In the geographic context, the four TCA maps cover the western end of the Central Cordillera of Colombia, between the Arma River in the south to the municipality of Olaya in the north, and between the Cauca River in the west to the Romeral cleaver range and the plains of Ovejas to the east. The studied zone covers an area of approximately 106 km long and 24 km wide (Figure 1a), configured in a south-north direction as follows: (1) Poblano plate, from 5° 41' 22"N bordering the Arma River, to 5° 53'54"N south of the municipalities of Venecia and Fredonia, between 75° 38'37"W and 75° 49'25"W; (2) Titiribí plate, between 5° 53'54"N south of the municipalities of Venecia and

Fredonia, to 6° 07'05"N south of the municipalities of Armenia and Angelópolis, from 75° 39'16"W and 75° 51'30"W; (3) Heliconia plate, between 6° 23'07"N south of the municipality of San Jerónimo and 6° 07'05"N south of the municipalities of Armenia and Angelópolis, in between 75° 37'26"W to 75° 51'54"W and; (4) Sopetrán plate, from 6° 23'07"N south of the municipality of San Jerónimo to 6° 39'00"N in the municipality of Olaya (formerly Sacaojal), between 75° 31'14"W and 75° 48'56"W.

Since its creation, the Bessel ellipsoid (1841) has been widely used in geodesy. Its function is based on various meridian arcs and data from continental geodetic networks of Europe, Russia and India's British Survey. In the early 20th century, such an ellipsoid was probably used by Emil Grosse for the production of the TCA maps. However, unfortunately, it is not accurately confirmed in Emil Grosse's cartographic information. On map 4 where the legend is reported, it is stated that "the topographic base of the map has been surveyed by Dr. Emil Grosse and Ing. Tulio Arbeláez G." (Grosse, 1926), without any additional information, and for this reason, in the present work the four TCA maps were digitized in that ellipsoid to WGS 84 datum, resulting in a unified map available in .kml format for viewing in Google Earth. The final map projected to WGS 84 was spatially and areally optimal. For example, the silhouette and meanders of the Cauca River conform to the western edge of the map (Figure 3), and likewise, the Romeral blade conforms to the eastern side of the map.

The TCA map has not undergone significant cartographic modifications in mapping lithologic units or mapping regional and local faults. However, the changes have been modifications in the definition of lithostratigraphic units and radiometric ages, partly due to the evolution of geochronological techniques. The most significant changes occurred in metamorphic and intrusive igneous rocks of the pre-Cenozoic age. For example, for the metamorphic rocks east of the Sopetrán and Romeral overthrusts (e.g., Romeral fault system), Emil Grosse separates contact aureoles (coronas in the original text), slates, and graphitic schists into independent units, while the three units are united in what is now called the Cajamarca Complex (González, 2001). A second example is found in the "Carboniferous Tertiary of Antioquia" concept, now called the Amagá Formation (González, 2001).

On the other hand, the most significant advance in geological knowledge in the TCA area is the radiometric ages of the pre-Cenozoic lithostratigraphic units. Results from U-Pb, Sm-Nd, and Ar-Ar dating have shown that the ages of the li-

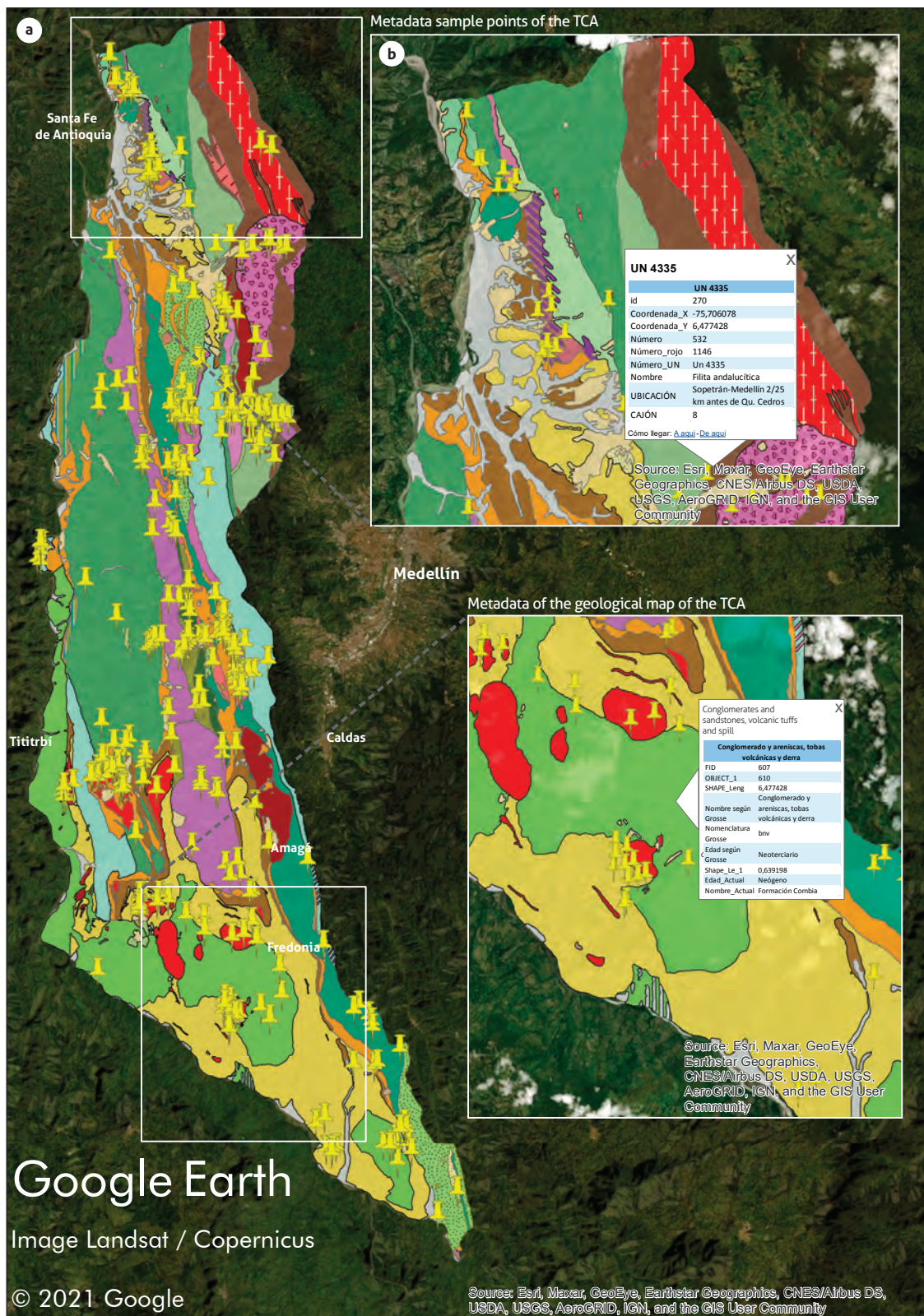


Figure 3. a) View of the geological map of the TCA in .kml format, in the Google Earth platform, with the location of the 456 cataloged and georeferenced rock thin section samples; b) Detailed metadata information of each thin section, showing the N and W coordinates, its numbering in the three different catalogues, name of the sample and location described by Dr. Grosse.

thostratigraphic units of the TCA range from 300 Ma to the Quaternary (Gómez et al., 2015), while for Grosse, the Cajamarca Complex, the Arquía Complex, the Sucre Amphibolites, the Sinifaná Metasedimentites, and the Angelópolis Ultramafites are assigned a Precambrian age (Grosse, 1926), following the recommendations of Dr. Robert Scheibe and his unpublished geological sketch of the area. This is because radiometric dating only had a profound development after World War II (White, 2013).

In the early 1920s, without the availability of radiometric dating and with an incipient advance on palynological studies at that time, Emil Grosse assigned an Eotertiary age to the Amagá Formation, an age approximate to those suggested by Van der Hammen (1958), who assigned a Middle Oligocene age to the Lower Member, based on palynomorphs found in claystones and coals, while Eocene palynomorphs are reported by Londoño et al. (2013) and Ramírez et al., (2015), proposing a middle to upper Eocene depositional interval for the Lower Member and middle to late Miocene age for the Upper Member. However, the age of the Amagá Formation remains controversial, and for example, Montes et al. (2015) and Lara et al. (2018) assign an age between ca. 15-13 Ma for the end of the Amagá Formation deposition. Similarly, Grosse assigned a Neotertiary age to the Combia Formation, which is temporally similar to the Miocene ages obtained by González (2001), Jaramillo et al. (2019), and

Weber et al. (2020). For this reason, the Grosse ages and the updated ages were taken into account to generate the metadata of the digitized layers, as shown in Figure 3.

3.2. Catalogue and interpretation of TCA thin sections

The geological sample collection of the TCA comprises hand specimens and thin sections, which were distributed among three academic institutions, including 1) the collection of the Royal Technical High School in Charlottenburg (Berlin Academy of Mines); 2) the Geological Institute of the University of Bonn and 3) the sample collection of the Escuela Nacional de Minas in Medellín, nowadays at the Faculty of Mines of the Universidad Nacional de Colombia in Medellín. For the thin section collection, a complete catalogue of the rock specimens was made, and thus, the information contained in the written part of the plates was transcribed (Figures 2a and 2b; Table 1). The collection of plates comprises 480 specimens, of which 456 are in good condition for petrographic analysis. The Emil Grosse collection was used for teaching until the 1990s at the University, and it is possible that this meant losses over time; furthermore, thin sections were not made for all hand specimens. On the other hand, the numbering of the 480 specimens assigned by Dr. Grosse for each plate ranges from number 1 to number 628, plus 7 alphabetically numbered plates; thus, to date, about 75% of the initially donated plates are preserved.

Table 1. Transcription translation to English, and interpretation of the TCA thin sections donated by Grosse to the Escuela Nacional de Minas

Sample No. (E. Grosse numbering, located at the top left)	Sample No. (located at the bottom right, in red)	Sample No. in UN catalog (located at the top of the section)	Transcription of the sample description by E. Grosse (i.e. upper thin section box).	Transcription of the location of the rock sample (i.e. bottom box of the thin section)	Interpretation of the north coordinate, based on the location description	Interpretation of the west coordinate, according to the location description
1	1798	N.A.	Candela Mountains. Hornblende augitic andesite	Hac. La Suiza; Block in the sleeve of the m	06° 04' 16,11"	75° 48' 16,37"
2	1796	UN 4422	Candela Mountains. Gabarro granite in the andesite	Hac. La Suiza; Block in the sleeve of the m	05° 54' 35,11"	75° 48' 29,29"
4	1756	UN 4406	Corcobado. Hornblende Andesite	1300 m S of Porvenir	05° 52' 54,41"	75° 42' 12,20"
5	1795	N.A.	Hornblende Andesite. Candela Mountains	La Suiza, blocks in the sleeve of the m	N.A.	N.A.
6	1759	UN 4409	Corcobado, Andesita hornblende	1200 m S of Porvenir. From the contact	05° 53' 14,49"	75° 42' 21,16"
8	1771	UN 4412	Arc. Piz. Modules at 5 cm from the contact	1200 m S of Porvenir	05° 52' 37,99"	75° 41' 54,71"
9	1790	UN 4419	Corcobado. Arc piz. Stained	550 m SW of Porvenir	05° 53' 22,23"	75° 42' 36,42"
10	1772	UN 4413	Corcobado. Arc. Piz. Modulated 20 cm	1200 m S of Porvenir	05° 52' 48,69"	75° 42' 39,26"
11	1774	UN 4415	Corcobado. Arc piz. Modulated 1 m from the contact	1200 m S of Porvenir C° to Cauca (sic.)	05° 52' 31,88"	75° 42' 19,41"

Missing numbers were specimens donated to other national and international academic institutions. Supplementary Material 4 presents detailed information on the 456 cataloged plates.

The information contained in the plates was transcribed as it appears in each specimen (i.e., *sensu stricto*, Table 1). In addition, the location of each plate was interpreted and georeferenced in the WGS 84 system, resulting in a list with geographical coordinates north and west, in degrees, minutes, and seconds (Table 1). This information is unpublished and allows us to unify geographically and with greater accuracy the samples of the TCA with the samples of the current literature. The information described above is detailed in supplementary materials 3 and 4, attached to this article. Subsequently, a photographic record was made of each specimen, and their respective photomicrographs were taken (Figures 2c and 2d) in a Leica petrographic microscope with a Leica DMC camera. In the photographic recording process, it was observed that the thin sections of the TCA are in good condition for future petrographic analysis. The slides have coverslips, which do not allow for electron microprobe analysis; however, the hand specimens are preserved in the Faculty of Mines of the Universidad Nacional de Colombia, Medellín.

To complement the transcription and interpretation of the information contained in all the available plates of the TCA, a photographic record of them was made, and their respective microphotography was taken, with plane-polarized light and crossed polarizers, to show graphically and in an unpublished way the color plates of the TCA manuscript (Figure 4a). The TCA map comprises 70 lithological units mapped by Grosse, equivalent to 18 lithostratigraphic units (Table 2), currently recognized by the Servicio Geológico Colombiano (Gómez et al., 2015). A single lithostratigraphic unit comprises one or several lithological units of the TCA. For example, for Grosse,

there are 13 different units of Neotertiary porphyritic intrusive rocks, which he separates in his map in detail, according to the different textural and mineral variations (e.g., andesite of indeterminate nature, andesite of varied development, micaceous andesite, hornblende andesite, augitic andesite, feldspathic basalt, augitic basalt, among others). At the same time, the Geological Survey corresponds to a unified group called Porphyritic Hypoabyssal Rocks (Figure 8c). In some cases, we have lithological units that are currently in disuse or do not have their equivalent in the regional literature because of their chemical implications; for example, Grosse uses the term *keratophyre* probably to refer to a volcanic rock of intermediate composition, which may have plagioclase richer in sodium than trachyte (Schermerhorn, 1973). Consider the terms *malchite* and *ebresite* used at the time by Grosse, but which have no equivalence today for classifying rocks.

Finally, 17 plates were selected from a total of 480 specimens, corresponding to 17 lithostratigraphic units (Quaternary alluvium and terraces were omitted), to generate the color photomicrographs of the original TCA specimens (Figures 4 to 8), where we listed 1) the metamorphic units, corresponding to Sucre Amphibolite, Palmitas Gneiss, Cajamarca Complex, Arquía Complex; 2) the Amagá Formation, Combia Formation and Sinifaná Metasedimentites; and 3) the igneous lithostratigraphic units, namely, Belmira Syntectonic Gneissic Intrusive, Quebradagrande Complex, Altavista Stock, Amagá Stock, Angelópolis Ultramaftites, Ovejas Batholith, Pueblito Gabbro, Pueblito Diorite, Heliconia Diorite, and Porphyritic Hypoabyssal Rocks.

Table 2. List of lithostratigraphic units mapped in the TCA and comparative ages assigned by Grosse vs. present ages

Lithological unit (Emil Grosse, 1926)	Lithostratigraphic Unit (Servicio Geológico Colombiano)	Age according to Grosse (1926)	Age updated	Figure No.
Zoisitic amphibolite	Amphibolites of Sucre	Pre Paleozoic	Paleozoic (González, 2001)	Figure 4b
Contact phyllite, contact crowns, shales and graphitic schists	Cajamarca Complex	Precambrian	240-230 Ma (Vinasco et al., 2006); 157-146 Ma (Blanco-Quintero et al., 2014).	Figure 5c
Lenticular granite, lenticular granite	Palmitas Gneiss	Pre Paleozoic	Permo-Triassic (González, 2001)	Figure 4c
Clay shales, phyllites and quartzites	Sinifaná Metasedimentites	Precambrian	Ordovician (González, 2001); Late Carboniferous to Early Triassic (Martens et al., 2012).	Figure 4d
Epidotized and uralitized diorite	Stock of Amagá	Eotertiary	221 Ma (Pérez, 1967); 232 Ma (Restrepo et al., 1991); Triassic (González, 2001).	Figure 6b
Peridotite (serpentine) - peridotite (harzburgite)	Ultramafites of Angelópolis	Pre Paleozoic	Lower Cretaceous; 166 Ma (González, 2001; Toussaint and Restrepo, 1978).	Figure 6c
Amphibolytic Gabbro	Pueblito Gabbro	Paleozoic	Lower Cretaceous; 166 Ma (González, 2001; Toussaint and Restrepo, 1978).	Figure 7a
Porphyritic diorite	Diorite of Pueblito	Paleozoic	Lower Cretaceous; 166 Ma (González, 2001; Toussaint and Restrepo, 1978).	Figure 7b
Augitic diorite	Altavista Stock	Eotertiary	Lower Cretaceous (González, 2001); 97 Ma (Cardona et al., 2020)	Figure 6a
Actinolitic shale	Arquía Complex	Precambrian	Lower Cretaceous; 137-112 Ma (Toussaint, 1996; Villagómez et al., 2011).	Figure 5a
Tufa agglomeratic	Quebradagrande Complex	Mesozoic	Lower Cretaceous; 105 Ma (González, 2001; Nivia et al., 2006; Toussaint and Restrepo, 1978).	Figure 5b
Quartz diorite, Idem acidic facies, keratophytic facies, basic facies	Diorite of Heliconia	Eotertiary	Upper Cretaceous (González, 2001)	Figure 7c
Lenticular granite	Gnesic Syntectonic Intrusive of Belmira	Pre Paleozoic	Permo-Triassic (González, 2001)	Figure 6d
Tonalite, quartziferous micaci-hornblende diorite: Ovejas-Poleal type	Batholith of Ovejas	Eotertiary	Upper Cretaceous (González, 2001)	Figure 6d
Carboniferous Tertiary of Antioquia (bcs, bcm, bci)	Amagá Formation	Tertiary	Middle Oligocene (Van de Hammen, 1958); Middle Eocene to Late Miocene (Londoño et al., 2013; Ramírez et al., 2015); end of deposition, ca. 15-13 Ma (Montes et al., 2015; Lara et al., 2018)	Figure 8a
Conglomerates, sandstones, volcanic tuffs, and eruptive spills (bns, bnv)	Combia Formation	Neotertiary	Neogene (~10-6 Ma) (González, 2001; Jaramillo et al., 2019; Weber, 2020).	Figure 8b
Andesite, micaceous andesite, hornblende andesite, augitic andesite, feldspathic basalt, augitic basalt, etc. (13 units in the TCA)	Neotertiary porphyry	Neotertiary	Neogene (González, 2001)	Figure 8c
Rubble, gravel, sand and subsoil covered with detrital detritus of the rocky slopes or boulders (a, df, d)	Recent alluvium and alluvial terraces	Quaternary	Quaternary (González, 2001; Mejía, 1984; Jaramillo-Zapata et al., 2014).	N.A.

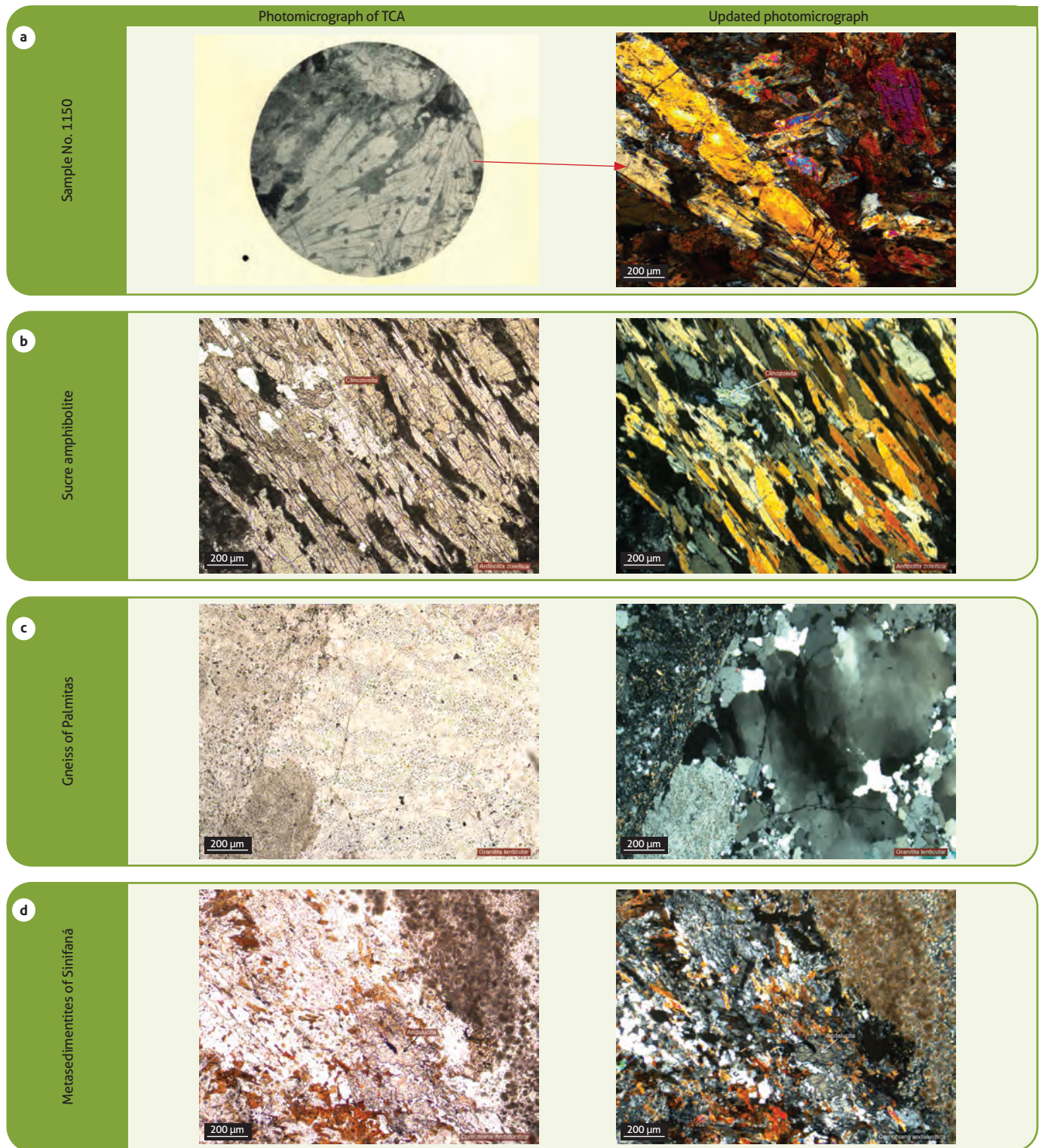


Figure 4. a) Photomicrograph of an andalusite and mica cornubian from the Cajamarca Complex, taken in shades of gray by Emil Grosse, compared with a color microphotograph of the same thin section, taken in the present work. Sample No. 1150 in Grosse's catalog; b-d) Pairs of photomicrographs with plane-polarized light and crossed polarizers, cataloged and transcribed according to Emil Grosse, corresponding to the following metamorphic lithostratigraphic units: b) Sucre amphibolite, sample No. 560, described as a sample of the Sucre Complex, sample No. 560, described as a "zoisitic amphibolite"; c) Gneiss of Palmitas, sample No. 476, catalogued as a "lenticular granite"; d) Metasedimentites of Sinifaná, sample No. 510, defined as a "cornubian andalusite".

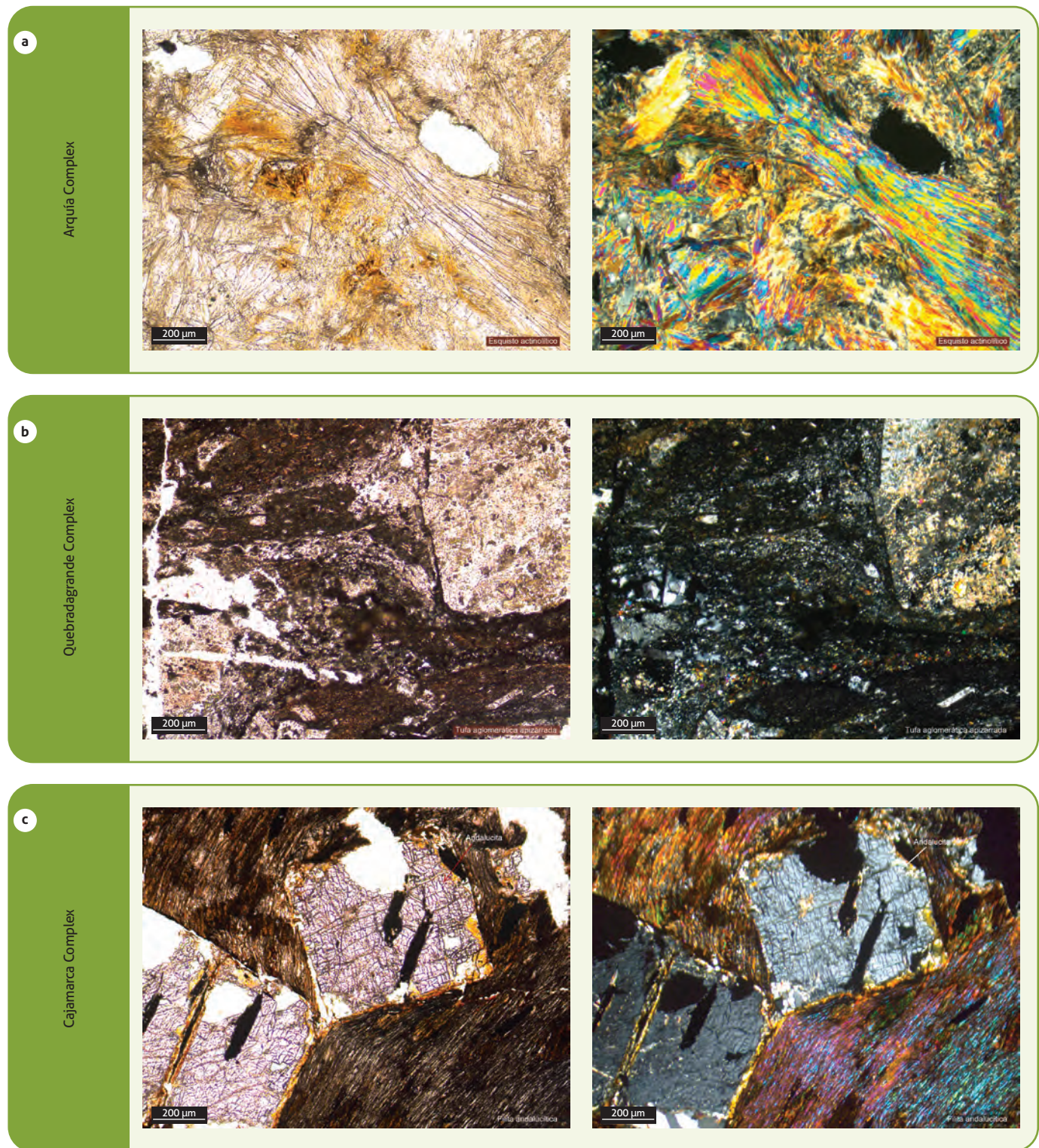


Figure 5. Pairs of photomicrographs with plane-polarized light and crossed polarizers, cataloged and transcribed according to Emil Grosse, corresponding to lithostratigraphic units denominated as complexes

a) Arquiá Complex, sample No. 287, described as an “actinolitic schist”; b) Quebradagrande Complex, sample No. 733, cataloged as an “agglomeratic tuff”; c) Cajamarca Complex Unit, sample No. 532, defined as a “contact phyllite”; d) Cajamarca Complex Unit, sample No. 532, defined as a “contact phyllite”; e) Quebradagrande Complex, sample No. 733, defined as an “agglomeratic tuff”.

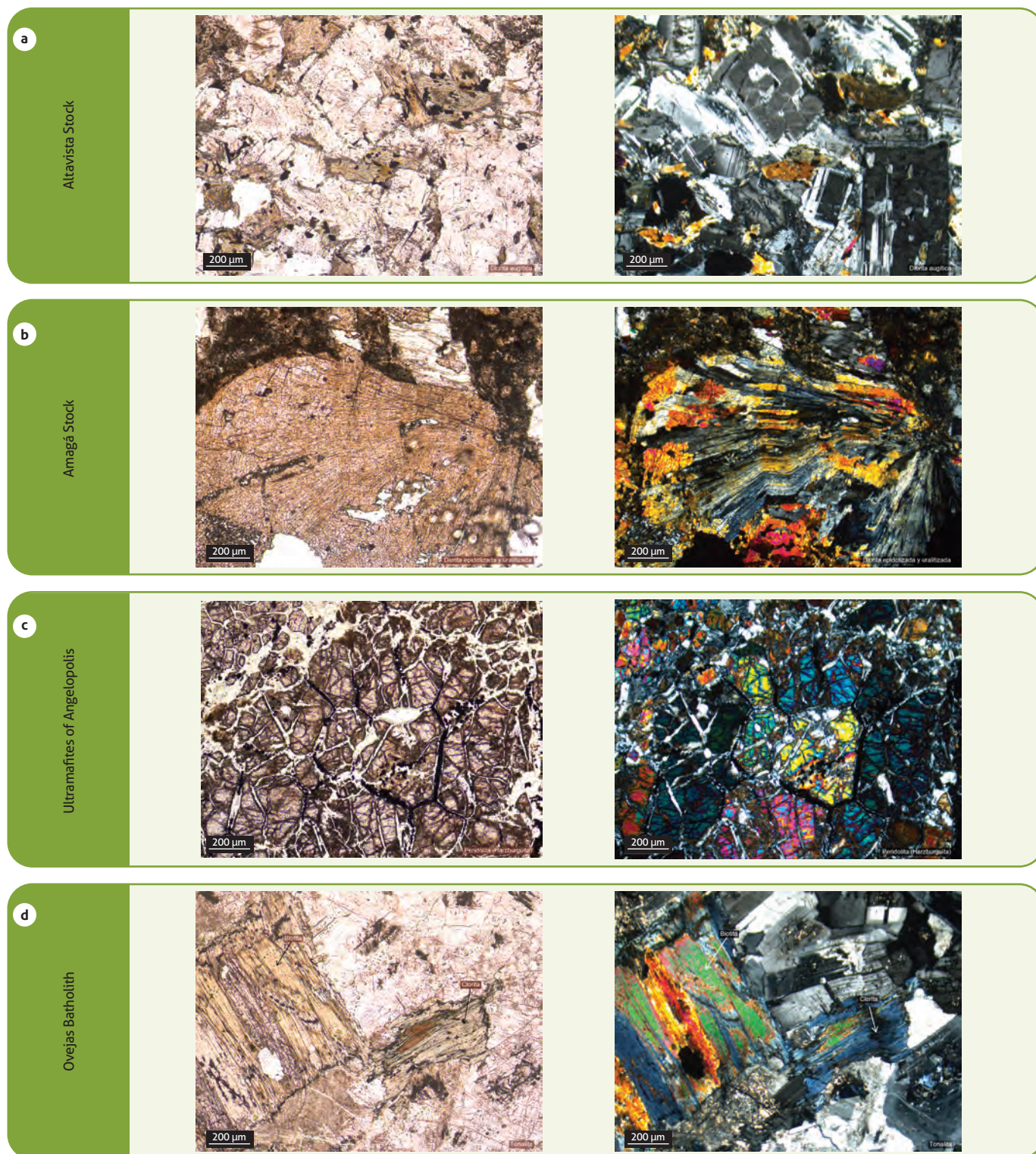


Figure 6. Pairs of photomicrographs with plane-polarized light and crossed polarizers, cataloged and transcribed according to Emil Grosse, corresponding to intrusive igneous lithostratigraphic units
a) Altavista Stock, sample No. 497, described as an “augitic diorite”; b) Amagá Stock, sample No. 406, defined as an “epidotized and uralitized diorite”; c) Ultramafites of Angelópolis, sample No. 535, catalogued as a “peridotite (harzburgite)”; d) Batolito de Ovejas, sample No. 522, corresponding to a “tonalite”.

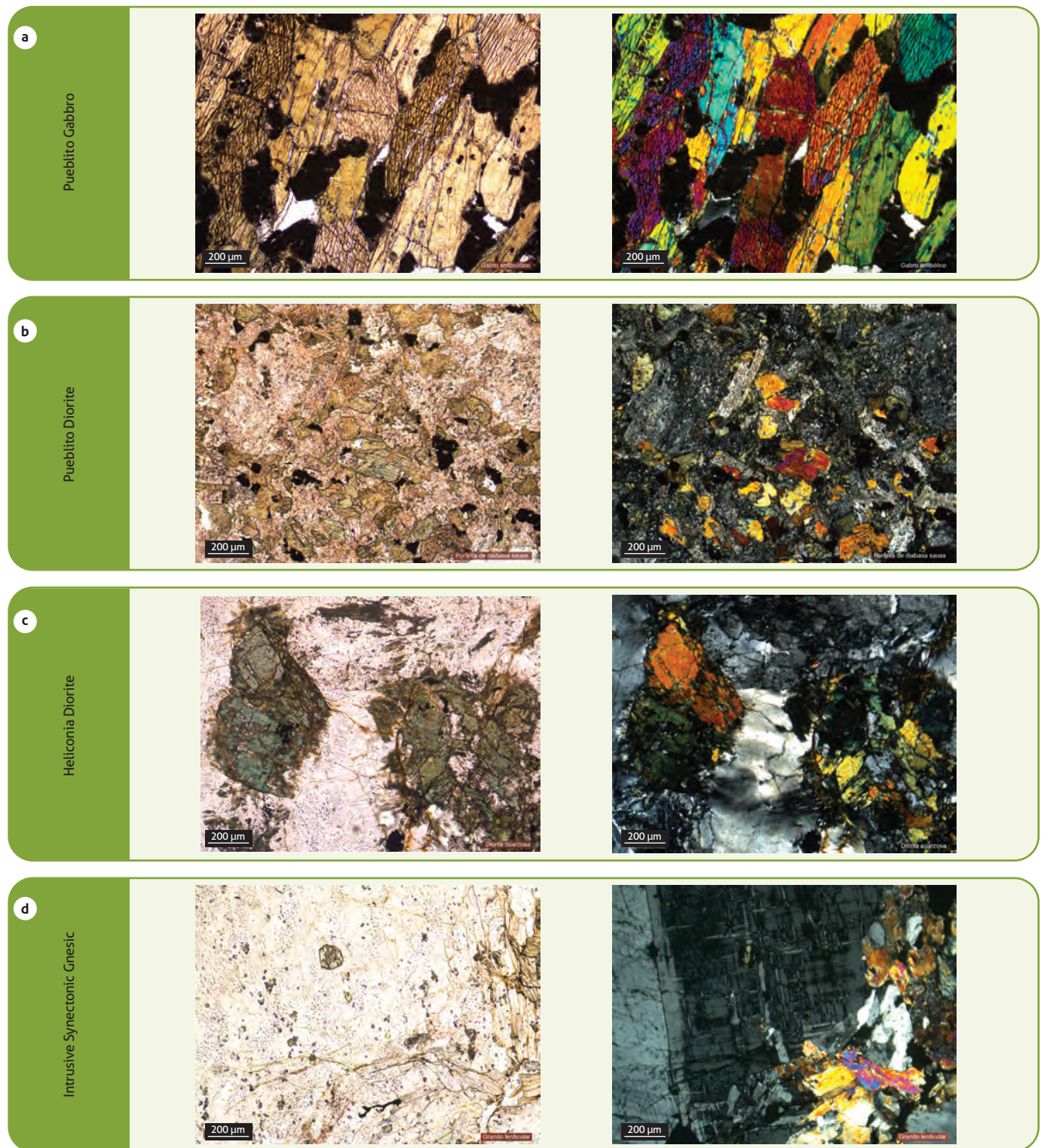


Figure 7. Pairs of photomicrographs with plane-polarized light and crossed polarizers, cataloged and transcribed according to Emil Grosse, corresponding to intrusive igneous lithostratigraphic units a) Puebla Gabbro, sample No. 300, described as an “amphibolitic gabbro”; b) Puebla Diorite, sample No. 449, defined as a “porphyritic diorite”; c) Heliconia Diorite, sample No. 389, corresponding to a “quartz diorite”; d) Intrusive Syntectonic Gnesic, sample No. 551, defined as a “lenticular granite”.

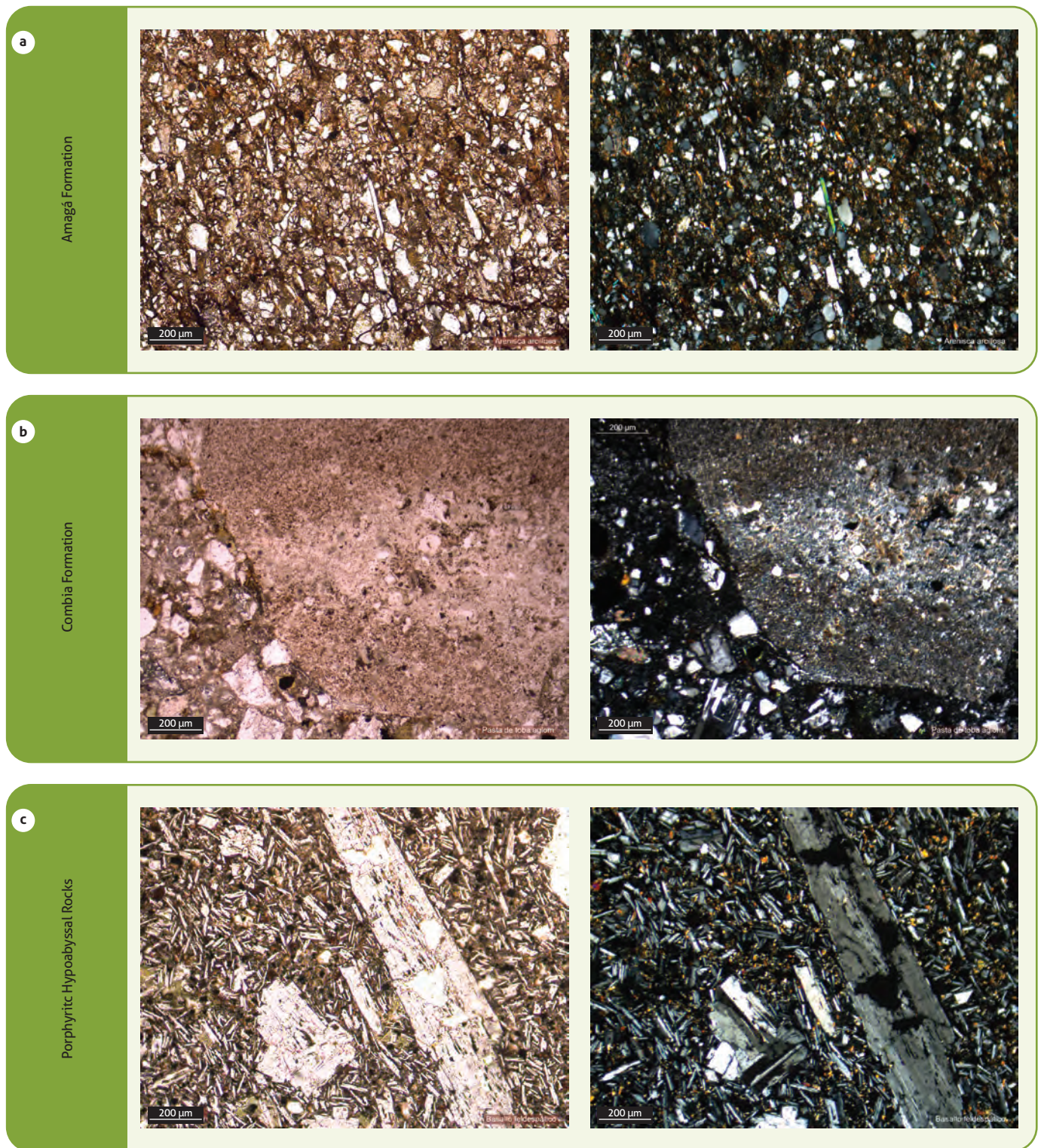


Figure 8. Pairs of photomicrographs with plane-polarized light and crossed polarizers, cataloged and transcribed according to Emil Grosse, corresponding to Tertiary lithostratigraphic units
a) Amagá Formation (Carboniferous Tertiary of Antioquia), specimen No. 391, described as a “clayey sandstone”; b) Combia Formation, sample No. 62, defined as a paste of “agglomeratic tuff”; c) Porphyritic Hypoabyssal Rocks, sample No. 48, corresponding to a “feldspathic basalt”.

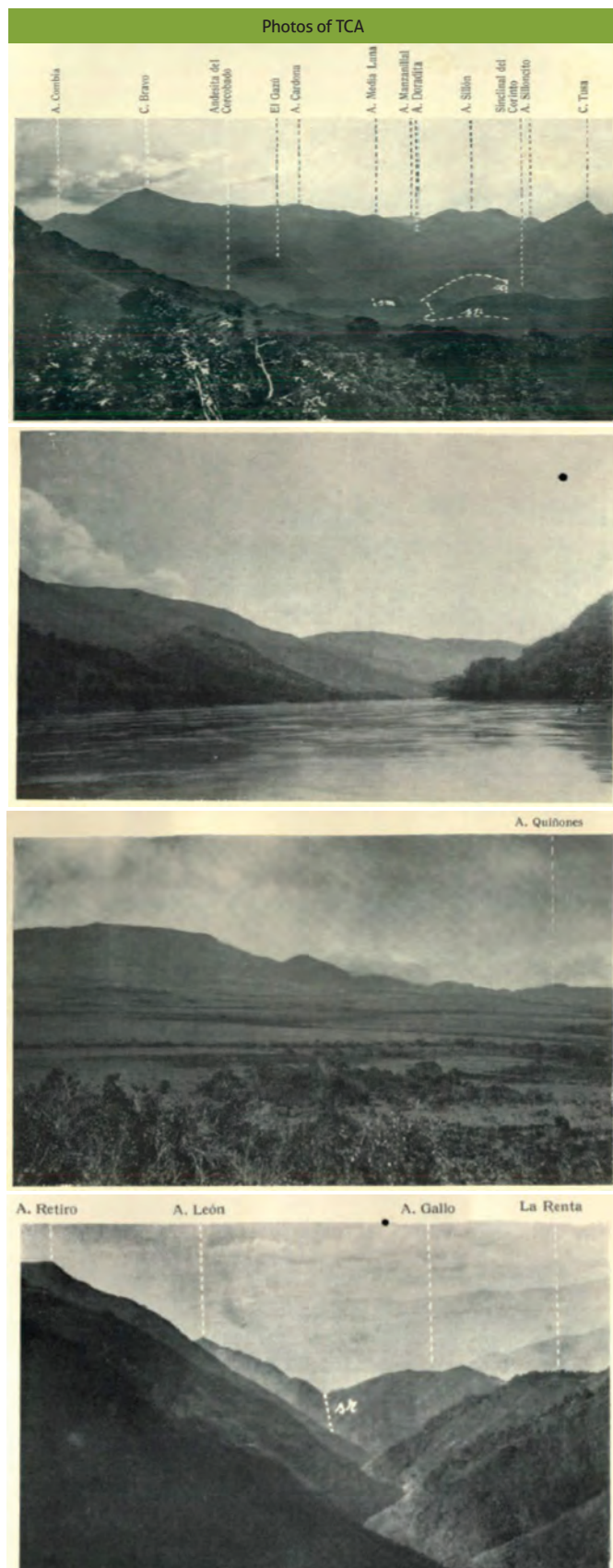
3.3. Multitemporal analysis of TCA images

To complement the cartographic, petrological, and structural work, Dr. Grosse left a photographic record of the most outstanding geomorphological features of the area associated with the TCA, which include: the great canyon of the Cauca River and its associated first- and second-order tributaries, the cliffs of La Pintada, Tusa hill, Bravo hill, the plains of Ovejas and the Boquerón area near the hill of Padre Amaya. The photographs show mainly landscapes of important geological information, taken from the highest altitude points in the area, such as the Alto de Quiñonez, Palo Blanco and Retiro, high and low slope hills, such as the Guayabal hill or the Monte Grande hill (Figures 9l and 9o), as well as the Cauca River and the Sinifaná, Nuarque and La Clara streams (Figures 9a, 9c, 9f, and 9g), and finally the urban centers of the municipalities of Ebéjico, Heliconia, and Sopetrán (Figures 9j and 9l). These photographs show in detail the most outstanding geomorphological and morphodynamic features of the area, such as the traces of faults and the formation of geofoms in silhouettes, sand bars, and meanders of rivers and their tributaries, plains, and lithological changes.

In order to take the exact photos where Dr. Grosse made his record, the description of the photograph was analyzed, and despite not having coordinates tied to the Bessel 1841 datum, it was possible to establish key reference points such as heights, hills, rivers, and streams, areas that were later corroborated in the field. The most difficult areas to find the exact location of were the first- and second-order streams and tributaries (e.g., Grosse's description: "the Las Juntas stream near the mouth of the Amagá stream"). Such descriptions were complicated at the beginning of the expedition due to the absence of a key reference point, such as hills, ridges, or high ground. However, satisfactory results were obtained in the end, resulting in

a photograph taken of the same point in the TCA, one hundred years after its publication (Figure 9b). The last problem encountered in taking photographs was that the access was restricted in many areas of interest because they were private properties or industrial areas.

When comparing the photographs, it can be seen that many of the rural and forested areas have remained little modified by man. For example, conservation of the landscape is evident in the Tablazo area of the Amagá-Heliconia watershed, and the high Gramal and Blanquizar cleaver in the municipality of Ebéjico (Figure 9n-o), and little anthropic intervention is observed in the alluvial terraces near the mouth of the Amagá stream in the Cauca river (Figure 9b). It is also observed that in some cases, there has been an increase in the vegetation and tree cover: for example, there is an increase in trees in the plains of Ovejas on the road between Bello and Sopetrán (Figure 9c), on the right margin of the western bridge of Santa Fe de Antioquia (Figure 9e) and in the high El Frisol, near the old road from Medellín to Sopetrán (Figure 9h). It is to be expected that the areas near the urban areas of the municipalities have a strong anthropic influence, such as road construction, fences, plantations and, in the specific case of Ebéjico, Sopetrán, and Heliconia, the increase of the urban limit, where the replacement of the houses in Tapia Pisada and Bahareque by brick and cement buildings can be observed (Figures 9c, 9j, and 9l). Finally, in the TCA photographs, there was little visibility of the overthrust zones (faults). In contrast, in the present photographs, the Amagá overthrust in the Heliconia basin can be better visualized (Figure 9i and 9j), the Sopetrán and La Sucumbí overthrusts on the Monte Grande hill, SW of Sopetrán (Figure 9l), and the Uvito and Piedecuesta overthrusts on the western slope of Roblal, in the Heliconia basin (Figure 9m).



Photos of TCA



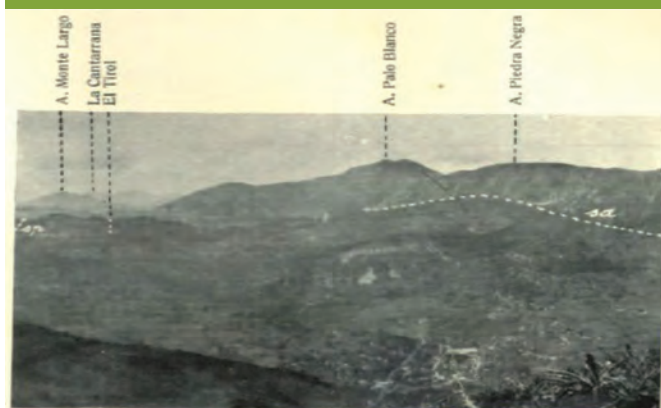
Catedral de Antioquia



Recent photos



Photos of TCA



Recent photos



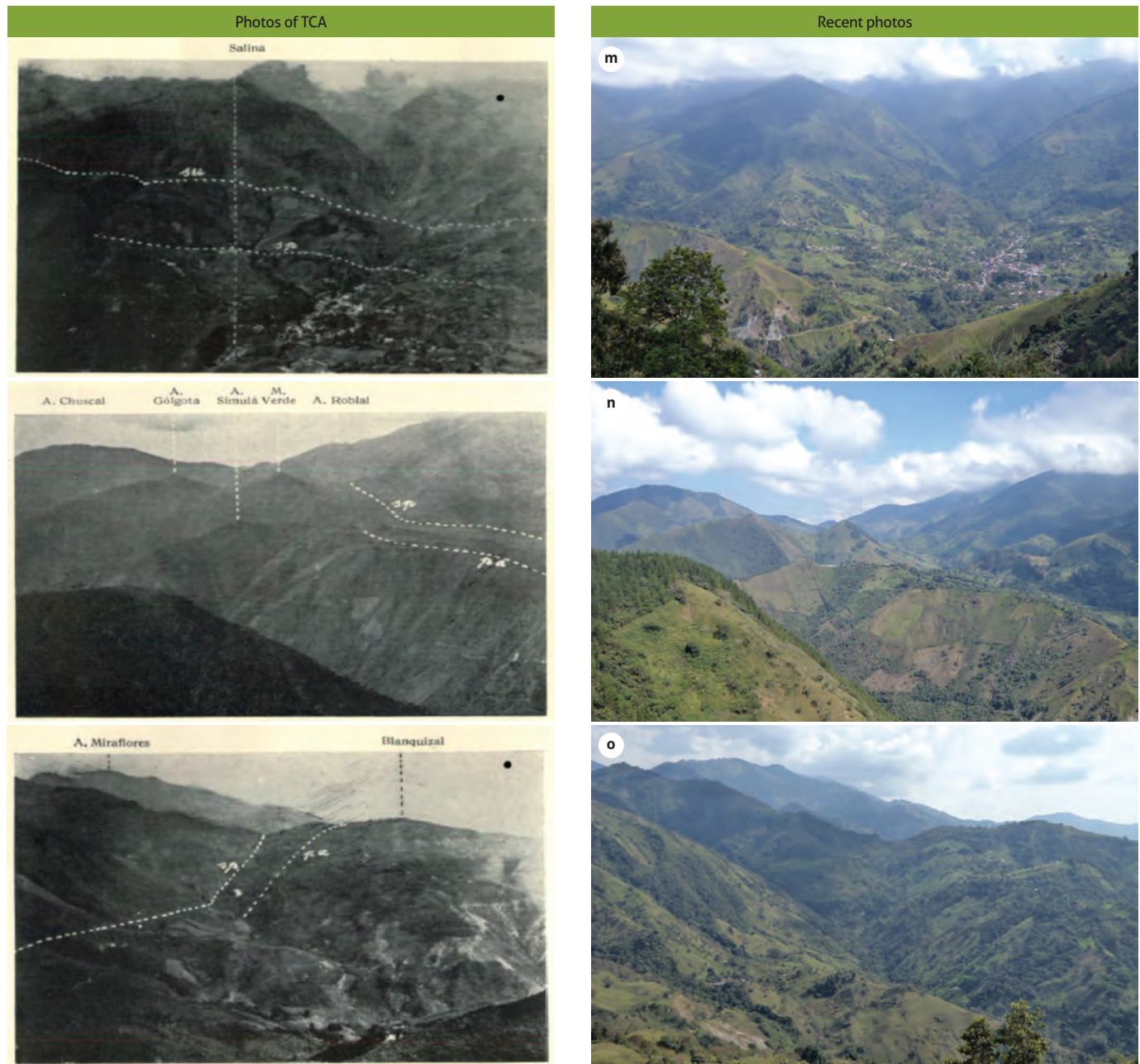


Figure 9. Pairs of photographs of the TCA taken by Emil Grosse and its present-day equivalent taken in the field

a) the mountainous region south of Sinifaná creek, as seen from the Manchal; b) Cauca river between the Paso de los Pobres pass and the mouth of Amagá creek; c) the Ovejas plains, as seen from the east (Bello-Sopetrán road); d) view along the Zaguá creek valley, from the Corral descent to Zaguá creek; e) view of the Cauca river and the Occidente bridge (right bank); f) bend of Nuarque creek, seen from upper Palo Grande; g) cut of Nuarque creek, near the buttress sector, seen from upper Palo Grande; h) La Frisola creek and upper Venteadero, seen to the south of upper El Frisol; i) Heliconia and the Heliconia-Amagá basin, S of Guaca creek, seen from the W foot of upper El Roblal; j) Heliconia basin S of Guaca creek, seen from the W foot of El Roblal; k) Sopetrán basin seen from a terrace SW of Sopetrán; l) Sopetrán on a terrace, Monte Grande hill and Sopetrana creek, seen SW of Sopetrán; m) view of the Heliconia basin, from the W slope of Roblal and Aburreña creek, seen from the upper El Calvario; n) El Tablazo and the furrow that continues the Amagá-Heliconia basin; o) W slope of the upper Gramal and Blanquizal, seen from the Guayabal hill.

4. CONCLUSIONS

The TCA is one of the most relevant classic works of the Antioquian and Colombian geology of the first half of the XX century, in which its rigorous execution, excellent field control, and meticulousness in the petrological and structural analyses stand out as one of the most valid and influential classic works, mainly for studies involving regional geology and economic geology.

In the research work presented, the four 1:50 000 scale maps of the TCA were digitized, and the cartographic projection was transferred, and linked to the WGS 84 datum to work digitally in the field. In addition, the sample of thin sections donated by Dr. Emil Grosse to the Escuela Nacional de Minas, now in the Museum of Geosciences, was cataloged. This catalog represents 75% of the total number of thin sections generated for the TCA.

The work carried out allows comparing the maps obtained 100 years ago with the current maps. The most important changes correspond to the results of geochronological dating for the 70 lithological units mapped by Grosse and in the subsequent conformation of 18 lithostratigraphic units recognized by the Servicio Geológico Colombiano, associated with the TCA study area. Likewise, a record of 480 photos of plates and photomicrographs was made to the collection of thin sections of Grosse, unpublished images of high patrimonial value. A multi-temporal analysis, carried out with the photographic record of the TCA, showed that, in a 100-year interval, there had been no significant anthropic change for the rural areas, and an increase in the vegetation and tree cover was observed. On the other hand, a high anthropic influence was shown for the urban area, among which the construction of roads, fences, plantations, and the increase of the urban boundary stand out.

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Supplementary material

Supplementary data for this article can be found online at <https://doi.org/10.32685/0120-1425/bol.geol.48.2.2021.570>

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