UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias de la Tierra, Energía y Ambiente

TÍTULO:

Stratigraphic and Sedimentological Analysis of the Upper Miocene Lacustrine and Fluvial Sediments of the Western Chota Basin, Ecuador.

Trabajo de integración curricular presentado como requisito para la obtención del título de Geólogo.

Autor:

Mario Fernando Humanante Guachilema

Tutor:

PhD. Germán Martín Merino

Urcuquí. Mayo, 2024.

AUTORÍA

Yo, **HUMANANTE GUACHILEMA MARIO FERNANDO**, con cédula de identidad **0401524343**, declaro que las ideas, juicios, valoraciones, interpretaciones, consultas bibliográficas, definiciones y conceptualizaciones expuestas en el presente trabajo; así cómo, los procedimientos y herramientas utilizadas en la investigación, son de absoluta responsabilidad de el/la autora (a) del trabajo de integración curricular. Así mismo, me acojo a los reglamentos internos de la Universidad de Investigación de Tecnología Experimental Yachay.

Urcuquí, mayo, 2024.

Mario Humanante
CI: 0401524343

AUTORIZACIÓN DE PUBLICACIÓN

Yo, **HUMANANTE GUACHILEMA MARIO FERNANDO,** con cédula de identidad **0401524343,** cedo a la Universidad de Investigación de Tecnología Experimental Yachay, los derechos de publicación de la presente obra, sin que deba haber un reconocimiento económico por este concepto. Declaro además que el texto del presente trabajo de titulación no podrá ser cedido a ninguna empresa editorial para su publicación u otros fines, sin contar previamente con la autorización escrita de la Universidad.

Asimismo, autorizo a la Universidad que realice la digitalización y publicación de este trabajo de integración curricular en el repositorio virtual, de conformidad a lo dispuesto en el Art. 144 de la Ley Orgánica de Educación Superior

Urcuquí, mayo, 2024.

Mario Humanante
CI: 0401524343

DEDICATION

This project is dedicated.

To my grandmother, Rosa Velarde.

Also, it is dedicated to my mother (Nelly) and my father (Mario Ricardo), who have never stopped believing in me. Moreover, my sister (Emily) and my brother (Richard) are next to them. It is to remind them that never is impossible to fight for a dream.

Additionally, it is dedicated to my uncle (Fernando), my aunt (Martha), mi cousins (Wilson, Darío, Jairo, Tania, Mario, Bryan, Fernando), who, with all my family, always supported me in difficult moments.

Lastly, this project is dedicated to me; for the courage that I have gained from my family, the resilience that has been instilled in me by different mentors, and the determination obtained through the different life adversities.

Mario Humanante

AKNOWLEDGMENT

I would like to express my gratitude to the Ph.D. Jorge Tor Álava, my first tutor of this project research. Who helped me to deal with the first and almost the final steps of this study.

Also, thank you to Rafael Almeida and Anna Foster for being mentors and always caring about me. I would like to say thank you to all my friends who helped me with my fieldwork adventures: Micaela Villaroel and Santiago Tirira (I know that you love “El Chota” the way I love it). I would like to say thank you to all my friends who helped me and supported me in this process of knowledge called university: Zulay Villaroel, Sebastián Gallegos (el Profe), Alejandro Paredes, Juan Gonzalez, Emilio Zambrano, Dayanara Caguana, Erika Fonseca, Maria Reinoso, Cristian Panchana, Milton Recalde, Carlos Lara, Nadine Nuñez, Anderson Rivadeneira, Luis Sarmiento, Victoria Suarez, Marcia Lema, Mariela Rodríguez, Andrea Terán, Marylin Figueroa, and Ángela Almeida.

Moreover, thank you to Germán Martín Merino for being my tutor and supported me on my last steps of my thesis project.

Finally, thank you to Ruth Zambrano for all the love and understanding.

Mario Humanante

RESUMEN

La cuenca andina intermontana del Chota en el norte de Ecuador comprende un basamento metamórfico cubierto por una secuencia de conglomerados, areniscas, limolitas, arcillolitas, lutitas y calizas fosilíferas que caracterizan diferentes eventos de deposición a lo largo del tiempo. Los depósitos lacustres y fluviales del Mioceno superior fueron definidos como Formación Chota por autores previos. La Formación Chota se divide en Formación Chota Oeste, la mayoría de los estudios centran su investigación en la Formación Chota Oriental o la Formación Chota en general. En esta investigación, fue posible crear y describir registros gráficos múltiples y contiguos. Asimismo, este estudio propone un modelo estratigráfico y sedimentológico para los sedimentos aluviales, fluviales y lacustres, compuestos principalmente por sedimentos clásticos y calcáreos, de la Formación Chota Oeste, entre la Montaña Loma Salada al Este y la Montaña Loma Gavilanes al Oeste, de la Cuenca Chota. Siguiendo estas líneas de evidencia, interpreté en este estudio que las secuencias sedimentarias identificadas en la Formación Chota Occidental de la cuenca Chota, con una edad que va desde el Mioceno Tardío hasta el Plioceno. Por otra parte, la Formación de Chota Occidental está compuesta por tres miembros (miembros inferiores, medios y superiores), cada uno de ellos con características particulares del entorno deposicional, litología y evolución. En este trabajo fue posible describir los miembros del Chota Inferior y Medio (construyendo 6 registros gráficos locales múltiples y 2 registros gráficos de miembros generales) para analizar la sucesión estratigráfica, facies, ambientes y evolución solo para los depósitos fluviales y lacustres del Mioceno tardío. La evolución del miembro Chota Inferior muestra una variación vertical de conglomerados a areniscas y limolitas, organizados en secuencias retrógradas de orden mayor, con facies y ambientes de abanico aluvial, ríos de arroyos trenzados, facies fluviales distales y delta proximal. Posteriormente, el Miembro Chota Medio muestra una variación vertical desde pocos conglomerados hasta areniscas, limolitas, calizas fosilíferas, arcillolitas y lutitas, organizadas en secuencias retrógradas en orden mayor con facies y ambientes desde facies arenosa, fluvial distal, delta, hasta facies lacustres de plataforma media, incluyendo probablemente una inundación máxima entre las lutitas, arcillolitas. Finalmente, el Miembro Chota Superior, no descrito en detalle en este estudio, está compuesto en su totalidad por secuencias progradacionales, (desde limolitas y areniscas de grano muy fino a fino), hasta facies fluviales, desde areniscas de grano alto a grueso a muy grueso y microconglomerados. Las facies, ambientes y litologías que ocurren en el Miembro Chota Inferior y el Miembro Chota Medio atestiguan el período de vida más tardío, durante el Mioceno tardío hasta el Plioceno inferior temprano, de la parte más occidental del entorno lacustre interior. Finalmente, este estudio permitió obtener un análisis consolidado del Miembro Chota Inferior y del Miembro Chota Medio, exhibiendo similitudes en sus composiciones minerales arcillosas, sugiriendo condiciones ambientales similares durante la deposición con ligeras variaciones.

Palabras clave: [Chota. Cuenca. Fluvial. Lacustre. Estratigrafía. Sedimentología.]

ABSTRACT

The Chota Intermontane Andean basin in northern Ecuador comprises of a metamorphic basement overlain by a sequence of conglomerates, sandstones, siltstones, claystones, shales, and fossiliferous limestones which characterizes different depositional events through time. Upper Miocene lacustrine and fluvial deposits were defined as Chota Formation by previous authors. Chota Formation is divided by into West Chota Formation mostly studies focus their research on East Chota Formation or the general basin, however this study focusses on the West Chota Formation. In this research, was possible to create and to describe multiple and contiguous graphic logs. Also, this study proposes a stratigraphic and sedimentological model for the alluvial, fluvial and lacustrine sediments, mainly compose by clastic and calcareous sediments, of the West Chota Formation, between Loma Salada Mountain to the East and Loma Gavilanes Mountain to the West, of the Chota Basin. Following these lines of evidence, I interpreted in this study that the sedimentary sequences identified in the West Chota Formation of the Chota basin, having an age ranging from Late Miocene to Pliocene. Moreover, West Chota Formation are composed by three members (Lower, Middle and Upper members), each of them with particular features of depositional environment, lithology, and evolution. In this work was possible to describe the Lower and Middle Chota members (constructing 6 multiple local graphic logs and 2 general members graphic logs) to analyze the stratigraphic succession, facies, environments, and evolution only for the Late Miocene fluvial and lacustrine deposits. The evolution of the Lower Chota member shows a vertical variation from conglomerates to sandstones and siltstones, organized in retrograding sequences at major order, with facies and environments from alluvial fan, braided stream rivers, distal fluvial, and proximal delta facies. Later the Middle Chota Member shows a vertical variation from few conglomerates to sandstones, siltstones, fossiliferous limestones, claystones and shales, organized in retrograding sequences at major order with facies and environments from sandy, distal fluvial, delta facies, up to lacustrine middle shelf facies, including probably a maximum flooding among the shales, claystones. Finally, the Upper Chota Member, not described in detail in this study, is composed entirely by progradational sequences, (from siltstones and very fine to fine grained sandstones), to Fluvial facies, from upper to coarse to very coarse grained sandstones and micro-conglomerates. The facies, environments and lithologies occurring in the Lower Chota Member and the Middle Chota Member testify the latest living period, during Late Miocene to early lower Pliocene times, of the westernmost part of the interior lacustrine setting. Finally, this study allowed to obtain a consolidated analysis of the Lower Chota Member and middle Chota member, exhibiting similarities in their clay mineral compositions, suggesting similar environmental conditions during deposition with slightly variations.

Key words: [Chota. Basin. Fluvial. Lacustrine. Stratigraphy. Sedimentology.]

PROBLEM STATEMENT

Lacustrine and fluvial deposits of the Chota basin were defined by Barragán et al. (1996) as the "Chota Unit" and later by Winkler et al. (2005) as the "Chota Formation." Chota Formation is divided by a north-south lahar into West Chota Formation and East Chota Formation. Most geological studies focus their research on the general view of the Chota basin or the East Chota Formation. The lack of detailed and recent studies on the West Chota Formation about stratigraphy, sedimentology, and geological mapping exploration makes this area relevant and important for geological research. Thus, this research analyzes the stratigraphical and sedimentological sequences composing the West Chota Formation (lacustrine and fluvial deposits of the West Chota Formation located between "Loma Gavilanes" and "Loma Salada" mountains).

OBJECTIVES

- Propose a stratigraphic model for lacustrine and fluvial deposits of the West Chota Formation between "Loma Gavilanes" and "Loma Salada" mountains.

- Describe the fluvial and lacustrine sedimentary sequences assigned to the West Chota Formation between "Loma Gavilanes" and "Loma Salada" mountains.

- Develop a petrological characterization of sandy samples for a macroscopic description in the laboratory.

- Develop an X-Ray Diffraction analysis on the laboratory to characterize muddy samples.

- Propose a general geological map and a cross section for the alluvial, fluvial and lacustrine deposits on the West Chota Formation.

GENERAL STRUCTURE OF THE THESIS

Chapter 1 - INTRODUCTION

Chapter 2 – REGIONAL GEOLOGY

Chapter 3 – METHODOLOGY

Chapter 4 – RESULTS

Chapter 5 – DISCUSSION

Chapter 6 – CONCLUSIONS

Chapter 7 – REFERENCES

ANNEXES

TABLE OF CONTENTS

TABLE OF FIGURES .... **x**

INDEX OF TABLES .... **xiv**

CHAPTER 1. INTRODUCTION **1**

CHAPTER 2. REGIONAL GEOLOGY **5**

2.1. Eastern Cordillera of Ecuador or Cordillera Real 5
2.2. Western Cordillera of Ecuador 7
2.3. Inter Andean Valley 9
2.3.1. Inter Andean Valley Basins 10
2.4. Chota Basin 12

CHAPTER 3. METHODOLOGY **18**

3.1. Geological Mapping 18
3.2. Stratigraphic Analysis 19
3.3. Sample Collection 20
3.4. Sedimentary Analysis 22
3.5. X-Ray Diffraction Analysis 23
3.5.1. X-Ray Diffraction Sample Preparation 24
3.5.2. X-Ray Diffraction Pattern Generation 27
3.6. Petrographic Analysis 29
3.6.1. Petrographic Analysis Under Binocular Stereoscope 30
3.7. Data Integration 31

CHAPTER 4. RESULTS **32**

4.1. Stratigraphic Results 33
4.1.1. Lower Chota Member 34
4.1.2. Middle Chota Member 44
4.2. Sample Collection Results 50
4.3. Petrographic Results 51
4.3.1. Bar Diagram Results 52
4.3.2. Triangular QFL Folk Diagram Results 56
4.4. X-Ray Diffraction Pattern Generation Results 60
4.5. Structural Cross Section 66

CHAPTER 5. DISCUSSION **67**

CHAPTER 6. CONCLUSIONS **71**

CHAPTER 7. REFERENCES **73**

ANNEXES **79**

TABLE OF FIGURES

Figure 1.-[Clastic main-sequences MS1 (fining upward.). Overlying main-sequence MS2 (coarsening-upper) identified in the Late Miocene alluvial, fluvial and lacustrine sedimentary infilling of the Chota intermontane basin (taken from Barragán et al., 1996).] 3

Figure 2.-[Clastic sequences identified in the Late Miocene alluvial, fluvial and lacustrine sedimentary infilling of the Chota intermontane basin (taken from Winkler et al., 2005).] 3

Figure 3.- [General map of the study area. A) General map view of Ecuador's country at the regional scale. On the east of the map at the continental territory of Ecuador, there is a black square showing an overview map of the location of the study area. B) Black square shows a zoom-in map of the north region of Ecuador. The map shows a World Topographic Base taken from ESRI. The map is highlighted: in purple is the Carchi province, and in brown is the Imbabura province. Between the boundaries of the Carchi and the Imbabura province, approximately 100 km northeast of Quito, a green square is locating the study area. C). Location map of the study area at a local scale. The green square shows the study area. White box labels show key information. The red with yellow line represents the "Panamericana" road. Blue lines in the North-South direction represent intermittent stream rivers. Finally, at the north, in the East-West direction, the Chota River.] 4

Figure 4.- [Geological physiographical provinces map of the Ecuador. At the bottom of the picture there is key information. (taken and modify from Vallejo et al., 2009).] 5

Figure 5. - [Lithotectonic units and major bounding faults composing the Eastern Cordillera of Ecuador. Key: IF, Ingapirca fault: PF, Peletec fault; BF, Baños fault; LF, Llanganates fault; CF-MF, Palanda-Mendez-Cosanga fault. (Taken from Aspden and Litherland, 1992.)] 6

Figure 6.-[Regional lithostratigraphy on the Coastal Forearc and the WCE (Western Cordillera). It shows Cretaceous to Neogene rocks. (taken from Vallejo et al., 2019).] 8

Figure 7.-[Neogene Interandean sedimentary basins of Ecuador are marked on black areas. Key words: D-G M., Dolores-Guayaquil megashear; Ch, Chota basin; G, Guayabamba basin; L (white), Latacunga; R, Riobamba basin; C, Cuenca basin; G, Girón–Santa Isabel basin; N, Nabón basin; L, Loja basin; V, Vilcabamba basin; Z, Zumba basin (taken from Marocco et al., 1995).] 10

Figure 8.-[Composite stratigraphy of the Late Miocene to Pleistocene Interandean Basins of Ecuador. Numbers for the Chota basin are ZFT and AFT ages in Ma; other numbers are K/Ar and 40Ar/39Ar ages in Ma. (taken from Winkler et al., 2005).] 11

Figure 9.-[Geologic map proposed by Euguez and Beate (1992), it shows in red color lines the main faults which control the development of the Chota basin. Key: Qal, Alluvial deposits; Qcr, reworked Cangagua; Qcg, primary Cangagua; Qvp, "San Vicente de Pusir" Landslaide; Qh,"El Hondon" Landslaide; Qpc,"Pillan Chiquito" Landslaide, Qt, "Tumbatu" Landslaide; Qav-I, Imbabura volcanics; Pch, Chachimbiro volcanics; Plya, Angochagua volcanics; HPlg, Granalotal unit; MPlpc, Peñas Colorads unit; Mplr, Santa Rosa unit; Mch,Chota unit; Ja, Amburqí Metamorphics (taken and modify from Reinoso. M., 2021).] 13

Figure 10.-[Geologic map from Barragán et al (1996) modified by Reinoso. M. (2019). Key: 1. Metamorphic basement, 2. Chota Member, 3. Santa Rosa Member, 4. Gavilanes Breccias, 5. Peñas Coloradas (brown) and Carpuela (black) Members, 6. Quaternary deposits, 7. Fault, 8. Normal contact, 9. Anticline axis, 10. Syncline axis, 11. Dipping, 12. Location of studied folds, 13. Location of studied microfractures sites. The pink square represents the study area of Reinoso. M. and Fonseca. E. (2019) Study. The yellow square represents the current study area of this research.] .14

Figure 11.-[Chota basin geologic map from Winkler et al., (2005). The red square represents the current study area of this research. At the right-down there is the legend which sow more details about the map.] 15
Figure 12.-[Chota basin geologic map from Reinoso, (2021). This map is focus on the East part of the Chota basin. The numbers are used to identify the faults and the letters to identify the folds. At the right part of the map there is the legend, which shows in detail the lithology and the different structures. Section A-A' represent a cross section.] .. 16
Figure 13.-[Base template for record stratigraphic log used in the study. Modified by Humanante. M. (2024). Base template is a merge between the Udden-Wentworth grain size classification for detritic rocks and the Dunham classification for limestones rocks. Key: cl, claystone; ss, siltstone; vf, very fine; f, fine; m, medium; c, coarse; vc, very coarse; C, Cobble; B, Boulder.] 19
Figure 14.-[Figure show the West Chota Formation area between "Loma Gavilanes" and "Loma Salada" mountains. Outcrop Section A, Outcrop Section B, and Outcrop Section C represents examples of the outcrop distribution in the study area. Blue line represents the Chota river. Yellow line represents E35 "Panamericana" road. At the right-bottom of the figure there is the legend and over it the north direction.] 20
Figure 15.-[A) Picture of a hammer 33-cm long Estwing Rip Claw Solid Steel Rock Pick. B.a) Black suitcase for rock transportation at the left. At the right-down synthetic bags. B.b) Plastic bags.] 21
Figure 16.-[A) Rock Cutting Machine "Precision Saw, series 090500". B) Rock samples in a cube shape status. C) Agate mortar (top) and a pestle agate with rubber coating (bot). D) Binocular stereoscope "OLYMPUS SZX16 of 1X lenses". E) Binocular stereoscope, "OLYMPUS SZ61".] 23
Figure 17.-[A) Rock samples in a plastic bag at the right. Beakers at the middle. Finally, at the left a Ohaus Pioneer weigh machine. B) Drying Stove brand POL-EKO model SLW 115 STD. C) Drying Stove with weighed mud samples in beakers).] 25
Figure 18.-[A) Protection equipment used in the Rock Preparation and Crushing Laboratory. At the top there is a safety googles glasses, at the bot right there is a dust filter mask, and to the left side there is an Anti-noise headphone. B) Vacuum cleaner machine employed in the cleaning processes. C) From left to right: A yellow-black compressed air. Orange brush with metal bristles. Blue brush with soft bristles. 70% alcohol (white). Paper cloths.] 26
Figure 19.-[A) Jaw Crusher, powered by an AC Motor speed control USMA24D, Model U9533. B) Rock fragments of a pebble size. C) UA V-Belt Driven Pulverizer, BICO model 242-53X2S (2 hp, 1ph, 110/220v, 60 Hz). D) 230 MESH Sieve made on steel. E) Finely ground sieved samples in little plastic bags).] 27
Figure 20.-[A) Rigaku Miniflex-600. B) Bragg-Brentano goniometer 8-position autosampler with six position filled by clay size grain sample. C) Clay size grain sieved samples in little plastic bags. D) Sample Holder Kit composed by: Planar glasses. Aluminum spoon (gray), Paintbrush (black). Aluminum Sample Holder (gray). E) Mud samples at clay size grain filled in Aluminum Sample Holders.] 28
Figure 21.-[A) Bar diagram expressing the total occurrence of minerals under the microscope (source: Tao et al., 2021). B) Classification of arenites and greywackes. Basic triangular diagram for the classification of sandstones (source: Folk, 1968, 1980).] 31
Figure 22.[Geologic map of the West Chota Formation area with principal geological structures. Map shows the different members identified. At the right-side legend explain more details.] 32
Figure 23.-[Map Location of Outcrops. Map in 1:3000 scale showing in purple the location of the graphic logs created for the sedimentological and provenance analysis of the West Chota Formation in the Chota basin. Letters over the outcrops indicate the name of it. To the right "Loma Salada" and to the left "Loma Gavilanes" mountains. At the North part of the map, near to the "Panamericana" road, there is the West Chota Town. Finally, legend located at the right-bot side.] 33

Figure 24.-[Propose stratigraphic column for Lower Chota Member. The stratigraphic record was performed from base to top for the Outcrop D, Outcrop C, Outcrop B, and Outcrop A (Fig. 25). Black dots represent samples used in petrographic studies. Black triangles represent samples used in X-Ray diffraction studies. Stratigraphic Log is reduced 15% of the 1:50 original recorded scale.] 35
Figure 25.-[Section N° 01 Graphic log at the lower-middle part of the Lower Chota Member. Stratigraphic Log is reduced 50% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Facies Codes (Annex 02, Table 06).] 37
Figure 26.-[Section N° 02 graphic log at the middle-upper part of the Lower Chota Member. Stratigraphic Log is reduced 75% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Facies Codes (Annex 02, Table 06).] 39
Figure 27.-[Section N° 03 graphic log at the upper part of the Lower Chota Member. Stratigraphic Log is reduced 75% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log Facies Codes (Annex 02, Table 06)] 41
Figure 28.-[Section N° 04 graphic log at the upper part of the Lower Chota Member. Stratigraphic Log is reduced 50% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Red structural data represents faults. Facies Codes (Annex 02, Table 06).] 43
Figure 29.-[Propose stratigraphic column for Middle Chota Member. The stratigraphic record was performed from base to top for the Outcrop E, Outcrop F, Outcrop G, Outcrop H, Outcrop I, Outcrop J, Outcrop K, Outcrop L, and Outcrop M (Fig. 25). Black dots represent samples used in petrographic studies. Black triangles represent samples used in X-Ray diffraction studies. Black structural data represents strike and dip measurements. Red structural data represents faults. Stratigraphic Log is reduced 15% of the 1:50 original recorded scale.] 45
Figure 30.-[Section N° 05 graphic log at the lower part of the Middle Chota Member. Stratigraphic Log is reduced 40% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Red structural data represents faults. Facies Codes (Annex 02, Table 06).] 47
Figure 31.-[Section N° 06 graphic log at the lower part of the Middle Chota Member. Stratigraphic Log is reduced 50% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Black structural data represents Strike and Dip. Facies Codes (Annex 02, Table 06).] 49
Figure 32.-[West Chota Formation Rock Composition. Total samples, n = 22. Bar diagram expressing the total occurrence of minerals and lithic fragments identified in 22 samples from the Lower Chota Member and the Middle Chota Member analyzed under the stereoscopic microscope. Key: Cement. Feldspar. Matrix (Mx). Metamorphic Quartz (Qmet). Volcanic Quartz (Qvolc). Lithics Volcanic (Lvolc). Sedimentary Lithics (Lsed). Metamorphic Lithics (Lmet). Heavy Minerals (HM). Base percentage mineral abundance (Table 04).] 53
Figure 33.-[Lower Chota Member Rock Composition. Total samples, n = 08. Bar diagram expressing the total occurrence of minerals and lithic fragments identified in 08 samples from the Lower Chota Member under the stereoscopic microscope. Key: Cement. Feldspar. Matrix (Mx). Metamorphic Quartz (Qmet). Volcanic Quartz (Qvolc). Lithics Volcanic (Lvolc). Sedimentary Lithics (Lsed). Metamorphic Lithics (Lmet). Heavy Minerals (HM).] 54
Figure 34.-[Middle Chota Member Rock Composition. Total samples, n = 14. Bar diagram expressing the total occurrence of minerals and lithic fragments identified in 14 samples from the Middle Chota Member under the stereoscopic microscope. Key: Cement. Feldspar. Matrix (Mx). Metamorphic Quartz (Qmet). Volcanic Quartz (Qvolc). Lithics Volcanic (Lvolc). Sedimentary Lithics (Lsed). Metamorphic Lithics (Lmet). Heavy Minerals (HM).] 55
Figure 35.-[QFL Folk diagram of the Lower Chota Member and Middle Chota Member sandstone samples. Classification of sandstones are in the triangular diagram QFL from Folk (1956) (Fig. 23.B). Blue dots represent the Lower Chota

Member samples. Red squares represent the Middle Chota Member samples. Key: Quartz content (Q). Feldspar content (F). Lithic content (L). Total samples, n = 22.] 56
Figure 36.-[QFL Folk diagram of the Lower Chota Member sandstone samples. Classification of sandstones are in the triangular diagram QFL from Folk (1956) (Fig. 23.B). Blue dots represent the Lower Chota Member samples. Key: Quartz content (Q). Feldspar content (F). Lithic content (L). Total samples, n = 08.] 57
Figure 37.-[QFL Folk diagram of the Middle Chota Member sandstone samples. Classification of sandstones are in the triangular diagram QFL from Folk (1956) (Fig. 23.B). Red squares represent the Middle Chota Member samples. Key: Quartz content (Q). Feldspar content (F). Lithic content (L). Total samples, n = 14.] 58
Figure 38.-[QFL Folk diagram showing the average value of the Middle Chota Member and the average value of the Lower Chota Member sandstone samples. Classification of sandstones are in the triangular diagram QFL from Folk (1956) (Fig. 23.B). Red square represents the average value from 14 samples of the Middle Chota Member. Blue dot represents the average value from 08 samples of the Lower Chota Member samples. Key: Quartz content (Q). Feldspar content (F). Lithic content (L). Total samples, n = 08.] 59
Figure 39.-[Provenance of sandstones of the Lower Chota Member and Middle Chota Member showing the compositional fields of tectonic provenance defined with the triangular diagram after Dickinson (1985). Key: Ave, average of composition or Mean; SD, standard deviation of a population of samples. n: total number of samples analyzed, n=12 samples for the Lower Chota Mb, and n=08 samples for Middle Chota Mb.] 60
Figure 40.-[X-Ray Diffraction bar diagram results of the 19 claystone samples from the Lower Chota Member and the Middle Chota Member of the West Chota Formation. Samples are represented in stratigraphic order from bottom to top.] 63
Figure 41.-[Proposed Lower Chota Member stratigraphic column with clay mineral abundance (Table 05). Black triangles represent samples used in XRD studies. Stratigraphic Log is reduced 15% of the 1:50 original recorded scale.] 64
Figure 42.-[Proposed Middle Chota Member stratigraphic column with clay mineral abundance (Table 05). Black triangles represent samples used in XRD studies. Stratigraphic Log is reduced 15% of the 1:50 original recorded scale.] 65
Figure 43.-[Structural Cross Section A-A'' (Pink line at Fig. 25). "Y" axis scale is amplified by 2 times the "X" axis scale. Data was extrapolated using stratigraphic thickness and measured altitudes.] 66
Figure 44.-[Petrographic description of igneous rock] 79
Figure 45.-[Sedimentary petrographic of limestones] 81
Figure 46.-[XRD pattern generation of the Lower Chota Member.] 82
Figure 47.-[XRD pattern generation of the Middle Chota Member.] 83

INDEX OF TABLES

Table 1.[Samples collected in the study. “Sample Name” represents the name assigned on field at the moment of collect the sample and the “Variable Name” is the name assigned for the study. In the section of Petrographic and X-Ray zero (0) means “no sample collected” and one (1) means “sample collected”. X and Y represent coordinates values (Datum: WGS 84. Projection: UTM 17N.).] 50

Table 2.-[Sedimentary petrographic descripted samples. “Variable Name” is the name assigned to the “Sample Name” for the study. Key: Cement. Feldspar. Matrix (Mx). Metamorphic Quartz (Qmet). Volcanic Quartz (Qvolc). Lithics Volcanic (Lvolc). Sedimentary Lithics (Lsed). Metamorphic Lithics (Lmet). Heavy Minerals (HM).] 51

Table 3.-[X-Ray Diffraction samples in stratigraphic log. “Chemistry Laboratory Name” represents the name for the (X, Y) pair data base developed for the Chemistry Laboratory of Characterization of materials, of the School of Chemical Sciences and Engineering, at Yachay Tech University. “Chemistry Variable Name” Name used for label the mud samples in the chemistry lab before X-Ray Diffraction analysis. “Sample Name” represents the name assigned on field at the moment of collect the sample. “Variable Name” is the name assigned for the study. Samples are represented in stratigraphic order from bottom to top.] 60

Table 4.-[Peak values for clay minerals identified in the X-Ray Diffraction Pattern graphics of the West Chota Formation. At the top of the table, from right to left; “Variable Name” or the Sample ID, after it there is the name of clay minerals founded. Samples are represented in stratigraphic order from bottom to top. Lower Chota Samples ID in red. Middle Chota Samples ID in blue.] 61

Table 5.-[Normalized peak values for clay minerals identified in the X-Ray Diffraction Pattern graphics of the West Chota Formation. At the top of the table, from right to left; “Variable Name” or the Sample ID, after it there is the name of clay minerals founded. Samples are represented in stratigraphic order from bottom to top. Lower Chota Samples ID in red. Middle Chota Samples ID in blue.] 62

Table 6.-[KEY Facies Codes] 80

CHAPTER 1. INTRODUCTION

The Andes mountain range is located in the western part bordering the South America continent, this mountain chain is the longest mountain range on continents (Boschman, 2021). In Ecuador, the Andean range extends from north to south with a length of approximately 600 km and a width of approximately 150-180 km (Coltorti & Ollier, 2000). During the Neogene epoch (late Miocene-early Pliocene) multiple: alluvial, lacustrine, and volcaniclastic continental sediments from the Andean orogeny were deposited along the inter-Andean valley on the multiple basins formed between the Western and Eastern cordillera of the Ecuadorian Andes (Barragán et al., 1996). Typically, a sedimentary basin is produced by the dynamism of tectonics and sedimentary processes. Facies, depositional environments, sediment characteristics, geometry, and occurrence can classify sedimentary basins. The most significant classification is by deposition, which follows global and regional tectonic configurations (Einsele, 2000).

The sedimentary basins of the inter-Andean valley present similar characteristics as they share the common geodynamics (controlled by the displacement of regional faults), volcanic inputs and sedimentary deformation (Barragán et al., 1996). In Ecuador, four intermontane sub-basins have been recognized. Thet are commonly referred to as the: Chota (located in the province of Imbabura-Carchi), Quito-Guayllabamba, Ambato-Latacunga and the Riobamba-Alausí basins (Winkler et al., 2005). The following study will focus on the Chota basin, which is located approximately 100 km northeast of Quito. Several aspects have been established about the importance of intramontane basins in stratigraphic, structural and paleoclimatic processes. For example, the evolution of the elevation, denudation and environmental conditions of the mountain ranges that surround the basin can be shown through sedimentary variations such as grain size, unconformities and provenance of sediments (Streit et al., 2015). However, basins are also conditioned by autogenous factors (internally generated factors such as deposition and erosion processes) and allogenic factors (linked to conditions of climate change, tectonism, and eustasy) that modify the geometry of the basin, the weathering, erosion, and sediment transport (Catuneanu, 2006).

Several studies of sedimentology and stratigraphy have been proposed over time from the Chota basin. However, the interpretation presented are highly variable. Studies recognize that the formation of inter-Andean basins can be associated to compression pulses related to transpressional movements and to the dextral displacement of the Western Cordillera with respect to the Eastern Cordillera (Lavenu et al., 1992; Winter & Lavenu, 1989). On the other hand, a sinistral ripping kinematic model was proposed based on the formation of overlapping basins since the displacement rate of the Eastern Cordillera was greater than that of the Western Cordillera (Tibaldi & Ferrari, 1992). It was proposed for the formation of the Chota basin as a W-E to WNW-ESE extensional regime as a geodynamic setting for the formation of the Chota Basin characterized by a transtensional tectonic regime and development of a molten depression. Later, it was compressed in a regime of the same orientation generated by the compressive tectonic regime change linked to reverse faults (Barragán et al., 1996). Finally, a relationship was established for the formation of the Chota basin with the formation of the inter-Andean valley in which the compressive stress regime has remained active since the origin of the basin (Winkler et al., 2005).

The Chota basin presents a 2.4m-thick sequence deposited on a Paleozoic meta-sedimentary substratum (Ambuquí Gp.). The Chota Basin sequence was defined by four stratigraphic formations: Chota, Santa Rosa, Peñas Coloradas, and Carpuela formations. Chota Formation, the oldest of the of these fourth is composed by the basal main-sequence (MS1) defined as fining-upper fluvial to lacustrine deposits, and the overlying main-sequence (MS2) defined as coursing-upward muddy deposits intercalated with conglomerates and sandstones (Fig. 01). Santa Rosa, Peñas Coloradas, and Carpuela formations are defined as coarsening-upper conglomeratic and sandy facies from alluvial fans (Barragán et al., 1996).

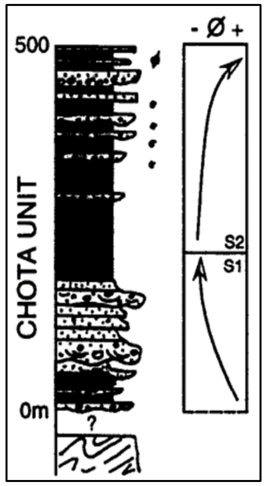

Figure 1.-[Clastic main-sequences MS1 (fining upward.). Overlying main-sequence MS2 (coarsening-upper) identified in the Late Miocene alluvial, fluvial and lacustrine sedimentary infilling of the Chota intermontane basin (taken from Barragán et al., 1996).]

Following the study of Winkler et al (2005), the Chota basin was presented as a 1,2 to 1,4 Km thick sequence of latest Miocene age, deposited over both: an oceanic plateau ultramafic basement (Pallatanga unit, Cretaceous, to the West) and a metamorphic basement (Guamote Unit, to the East), composed by three stratigraphic units separated by a south-north lahar flow, these formations are: the Peñas Coloradas. Fm. (defined as alluvial fan with volcanoclastic breccias deposits, to the East), Chota. Fm. (defined as fluvial to lacustrine deposits, to the West and to the East), and Santa Rosa. Fm. (defined as fluvial to alluvial fan deposit, to the West) (Fig. 02). (Winkler et al., 2005).

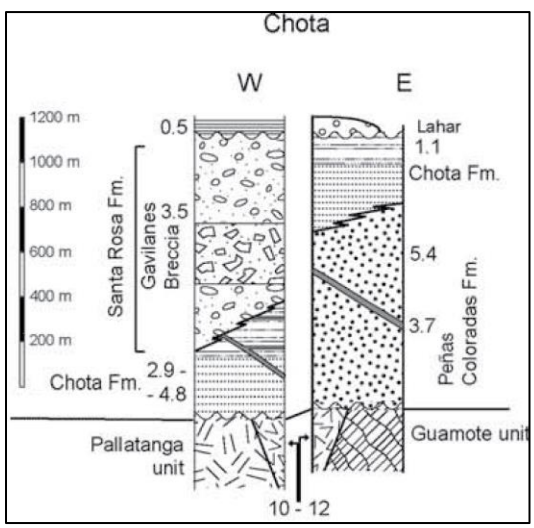

Figure 2.-[Clastic sequences identified in the Late Miocene alluvial, fluvial and lacustrine sedimentary infilling of the Chota intermontane basin (taken from Winkler et al., 2005).]

The Chota basin has several key sequences, conformed by lacustrine, fluvial, and alluvial deposits, these deposits are very important since it determines how was the evolution process of the basin. This study has as its main objective the analysis of the stratigraphic and sedimentological sequences composing the West Chota Formation of the Chota basin (Fig. 03). The stratigraphic and sedimentological analysis consists of recording and describing the alluvial, fluvial, and lacustrine sediments between the "Loma Gavilanes" mountain, to the West, and the Loma Salada mountain, to the East, on the Chota basin. In addition, I opted to created graphic records that describe texture of sediments -clastic and calcareous too-, lithology, facies, sedimentary structures, body and trace fossils, that contribute to establish future correlations. Also, through the study of mineral composition of sandy sediments under the microscope and clay samples via X-Ray Diffraction analysis, on samples collected in the field. And finally, through field work, I propose a geologic map of the Chota West Formation, showing contacts, structural data, and the corresponded cross section.

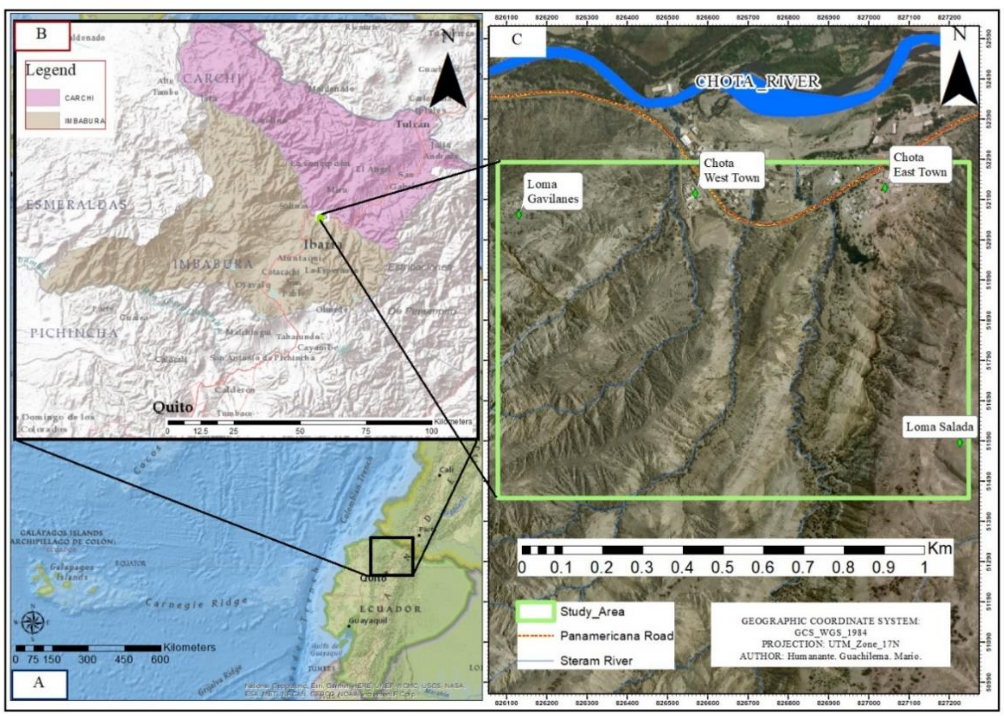

Figure 3.- [General map of the study area. A) General map view of Ecuador's country at the regional scale. On the east of the map at the continental territory of Ecuador, there is a black square showing an overview map of the location of the study area. B) Black square shows a zoom-in map of the north region of Ecuador. The map shows a World Topographic Base taken from ESRI. The map is highlighted: in purple is the Carchi province, and in brown is the Imbabura province. Between the boundaries of the Carchi and the Imbabura province, approximately 100 km northeast of Quito, a green square is locating the study area. C). Location map of the study area at a local scale. The green square shows the study area. White box labels show key information. The red with yellow line represents the "Panamericana" road. Blue lines in the North-South direction represent intermittent stream rivers. Finally, at the north, in the East-West direction, the Chota River.]

CHAPTER 2. REGIONAL GEOLOGY

The geological evolution in the region followed different processes such as: accretions, collisions, deposition of sedimentary sequences, orogenic events (Grenvillian orogeny at ~ 1000 Ma, Hercynian and Andean orogenic phases), and associated metamorphic events that were modifying the Amazonian Craton and South America through time (Cediel & Shaw, 2019). Specifically, in Ecuador, these successive processes created several geological physiographical provinces: Coastal Plain (CP), Western Cordillera of Ecuador (WCE), Inter Andean Valley (IAV), Eastern Cordillera of Ecuador (ECE), and Andean Amazon Basin, formed by the proximal deformed belt of the Subandean-zone and the Oriente basin (Fig. 04) (Martin-Gombojav & Winkler, 2008; Vallejo et al., 2009).

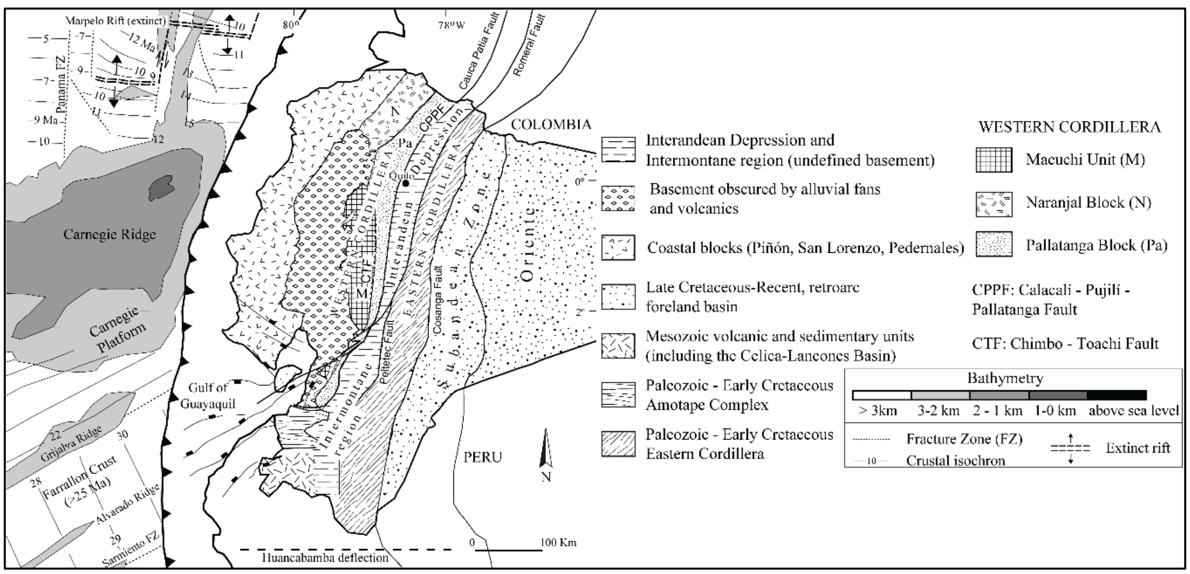

Figure 4.- [Geological physiographical provinces map of the Ecuador. At the bottom of the picture there is key information. (taken and modify from Vallejo et al., 2009).]

2.1. Eastern Cordillera of Ecuador or Cordillera Real

The Cordillera Real of Ecuador (CRE), or the Eastern Cordillera (EC), composed of pre-Cambrian basement and along-strike sublinear Paleozoic metamorphic belts intruded by granitoids (Aspden & Litherland, 1992; Hughes & Pilatasig, 2002). It defines five litho-tectonostratigraphic divisions of Permo-Triassic age (synchronous with the Pangea formation period) (Aspden et al., 1992; Aspden & Litherland, 1992; Noble et al., 1997). There five lithotectonic divisions are, from West to East: Guamote, Alao, Loja, Salado, and Zamora divisions separated by major bounding faults (Peltetec, Baños, Llanganates, and Palanda-Méndez-Cosanga faults, respectively) (Fig. 07) (Aspden & Litherland, 1992). These lithotectonic terranes were defined by compressional processes, subsequent metamorphism, and intrusion mechanisms through time. The formation of continental arcs and magmatic activity enhanced the magmatic activity during the consolidation of the lithotectonic divisions of the Cordillera Real. S-type granitoids from Tres Lagunas Unit intruded the Paleozoic Loja terrain during Upper Triassic (227,3 Ma, U/Pb) (Noble et al., 1997). The formation of the Misahualli continental arc, during the middle to late Jurassic, created an active volcanic regime, enhancing the deposition of sedimentary sequences and the emplacement of I-type granitoids on the Alao terrane.

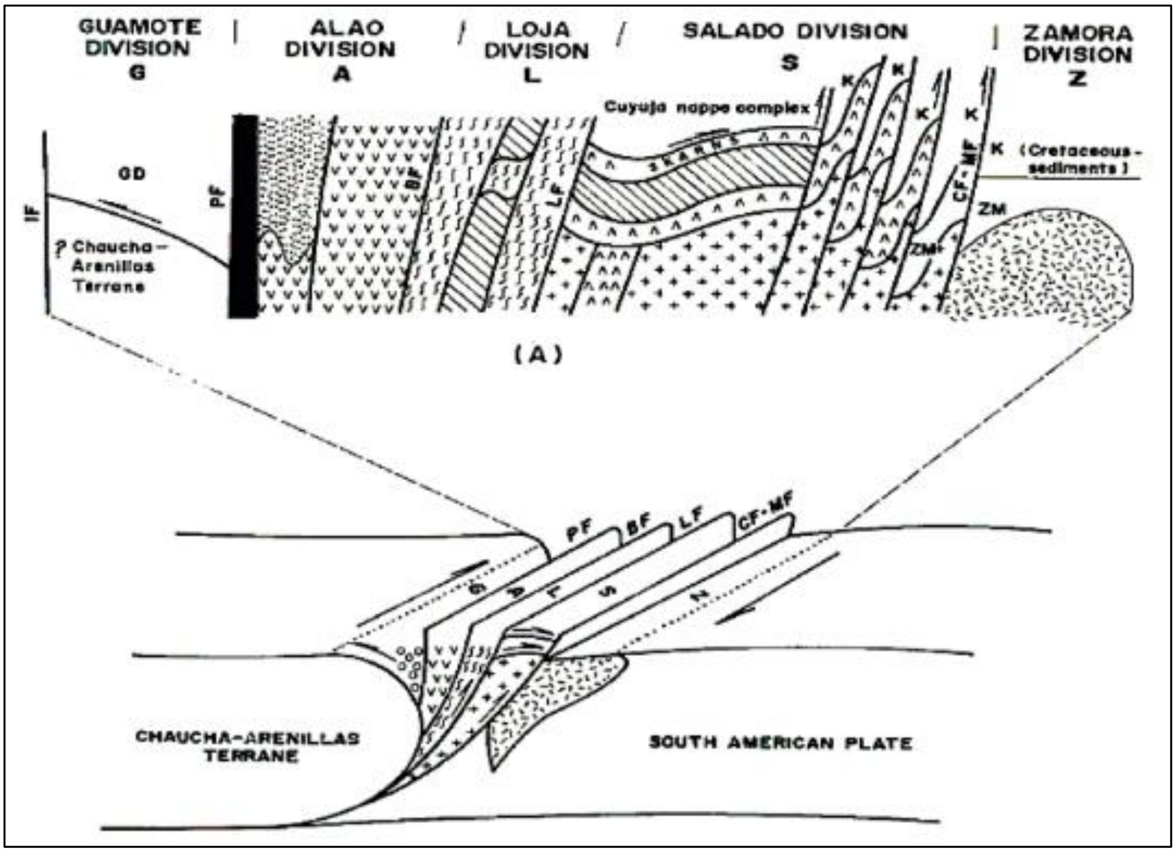

Figure 5. - [Lithotectonic units and major bounding faults composing the Eastern Cordillera of Ecuador. Key: IF, Ingapirca fault: PF, Peletec fault; BF, Baños fault; LF, Llanganates fault; CF-MF, Palanda-Mendez-Cosanga fault. (Taken from Aspden and Litherland, 1992.)]

The subsequent accretion of the arc and associated sediments took place during the Jurassic-Cretaceous Peltetec event (Martin-Gombojav & Winkler, 2008; Villares et al., 2020). The collision of these arc sequences and fragments of the Caribbean plateau during the late Cretaceous (Campanian - Maastrichtian) to the continental margin increased the exhumation rate of the Cordillera Real (Jaillard et al., 2009), producing a half-graben regime on the western part and enhancing the deposition of detrital sediments in both, the Oriente basin to the East and the half graben to the west (now the Interandean depression) (Luzieux et al., 2006; Spikings et al., 2005; Vallejo et al., 2006).

2.2. Western Cordillera of Ecuador

The Western Cordillera of Ecuador (WCE) was formed by a compressive tectonic regime. WCE consist of oceanic plateaus, that accreted the South America plate margin in the Late Cretaceous. (Pardo-Trujillo et al., 2020; Jaillard et al., 2009). The WCE has an altitude between 1,000 and 6,300 meters above sea level. It is limited to the east by the Calacalí-Pujilí-Pallatanga fault and to the west by the coastal plain (Fig 04) (Spikings et al., 2005; Vallejo, 2007; Vallejo et al., 2019). There is evidence of two oceanic terranes during the period of collision and accretion, those are called Pallatanga and Macuchi terranes (Fig 08). The acretion of the Pallatanga terrane to the western continental margin occurring during the Late Cretaceous and produced the first period of oceanic collision-accretion 85-80 Ma ago. The second period of oceanic collision-accretion happened between the Macuchi and Pallatanga terranes during the Eocene 40-35 Ma ago (Hughes & Pilatasig, 2002; Kerr et al., 2002; Spikings et al., 2005; Toro Álava & Jaillard, 2005; Vallejo, 2007; Vallejo et al., 2019).

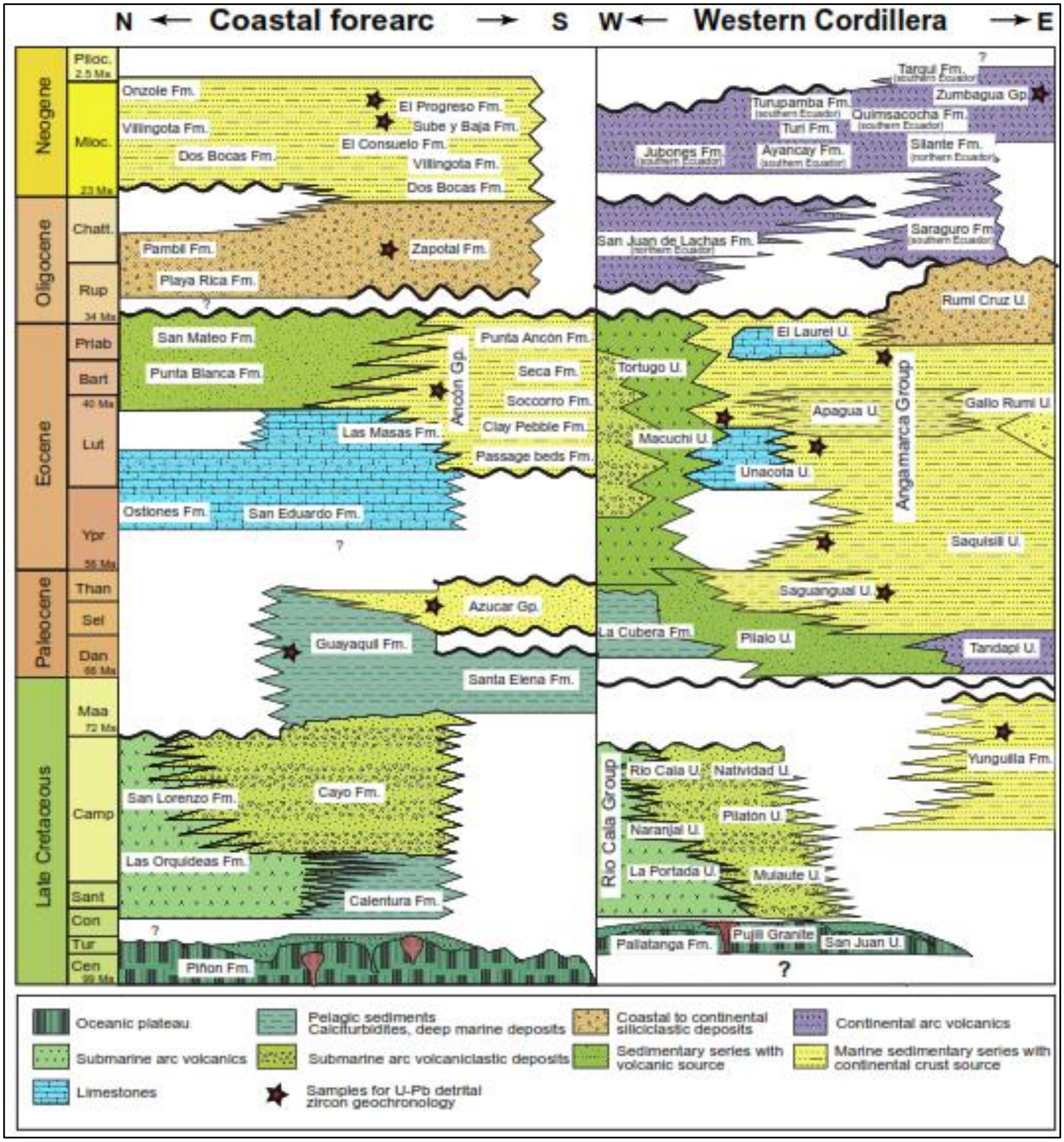

Figure 6.-[Regional lithostratigraphy on the Coastal Forearc and the WCE (Western Cordillera). It shows Cretaceous to Neogene rocks. (taken from Vallejo et al., 2019).]

In addition, the WCE is composed of: sub-green schist facies, oceanic plateau basalts. Followed by submarine arc volcanic and submarine arc volcanic deposits late cretaceous Campanian. Overlayed by marine shales, calci-turbidites, platform graywackes and fan-delta conglomerates (Yunguilla Gp., middle Campanian to early Maastrichtian). Folloy by marine quartz-rich low density turbidites (Saquisili U. and Gallo Rumi U, late Paleocene to late Eocene). Also, there is a basaltic to andesitic oceanic arc segment (late Maastrichtian to late Eocene, Machuchi U.). And shallow marine limestones (latest early Eocene, Apagua U.) Overlaying Saquisilli. U., Gallo Rumi U., and Apagua. U. there is chert and quartz-rich fluvial to shallow marine sandstones and conglomerates (late Eocene, Rumi Cruz U.). Finally, at the top Saraguro Fm., Silante Fm., and Zumbagua GP. Continentakl arc volcanics. (Toro Álava, 2007; Toro Álava and Jaillard, 2004; Hughes & Pilatasig, 2002; Jaillard et al., 2005; Vallejo et al., 2019; Pardo-Trujillo et al., 2020).

2.3. Inter Andean Valley

The Inter Andean Valley (IAV) is a Late Miocene-Pleistocene tectonic depression located between the WCE and the ECE. The IAV is a compressional basin delimited by fault systems, the Pallatanga-Calacali-Pujili to the West and the Peltetec fault to the East (Lavenu et al., 1995ab; Vallejo et al., 2009). The aperture of the inter-Andean Valley was driven by major strike-slip movements along the Calacalí-Pallatanga fault during the Late Miocene at ~ 6 - 5 Ma and finished by a compressive inversion during middle Pleistocene (Hungerbuhler et al., 1995; Villagómez, 2003). The sedimentary basins located in the IAV are composed of reworked material, alluvial, lacustrine, volcaniclastic, and metamorphic rocks (Barragán et al., 1996; Hungerbuhler et al., 1995; Marocco et al., 1995). The most recognized intermontane basins in Ecuador are, from North to South: Chota, Guayllabamba, Latacunga-Ambato, Riobamba, from Late Miocene to Pleistocene, and Cuenca, Giron-Santa Isabel, Nabón, Loja, Vilcabamba - Malacatos and Zumba, from Eocene to late Miocene (Fig 08) (Marocco et al., 1995, Barragán et al., 1996).

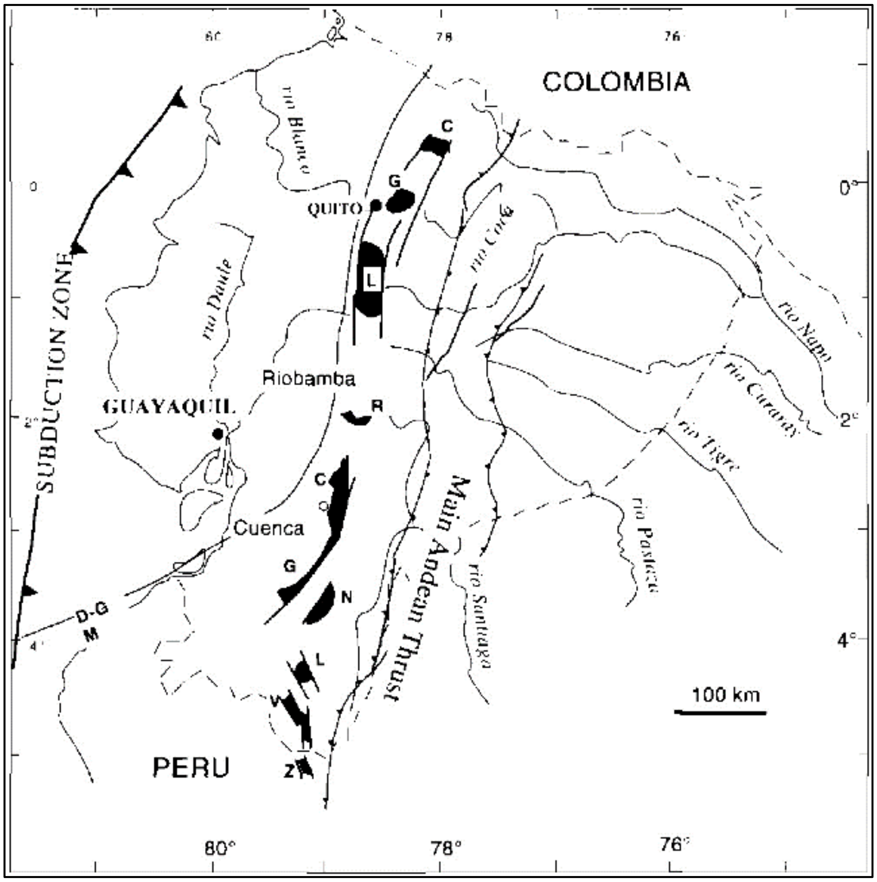

Figure 7.-[Neogene Interandean sedimentary basins of Ecuador are marked on black areas. Key words: D-G M., Dolores-Guayaquil megashear; Ch, Chota basin; G, Guayabamba basin; L (white), Latacunga; R, Riobamba basin; C, Cuenca basin; G, Girón–Santa Isabel basin; N, Nabón basin; L, Loja basin; V, Vilcabamba basin; Z, Zumba basin (taken from Marocco et al., 1995).]

2.3.1. Inter Andean Valley Basins

This section is dedicated to mention a brief description about different Ecuadorian intermontane basins. The Chota basin is located in the northernmost Ecuadorian Andes, in the Imbabura province (Fig 09), containing the best stratigraphic record of the northern Inter Andean Valley (Fig 10) (Marocco et al., 1995; Tibaldi & Ferrari, 1992). This basin will be explained in detail in the next section. From North to South direction the next basin in the IAV is the Guayllabamba basin. It is located in the central part of continental Ecuador, Pichincha province (Fig 09). This basin comprises: volcanic, fluvial, alluvial, and lacustrine deposits interbedded with deltaic, and turbidite deposits (Fig 10) (Villagómez, 2003). The next basin is the Latacunga-Ambato basin. It is located South direction of Guayllabamba basin (Fig 09). It is limited to the East by the Pisayambo fault and to the West by the La

Victoria fault. It is composed of four different units with ~ 500 m of the total thickness. The first unit comprises lahars, pyroclastic flows, andesitic lavas, lacustrine and fluvial deposits; while unconsolidated fluviatile and lacustrine deposits compose the second unit; and finally, the lasts units contain unconsolidated pyroclastic tuffs (Fig 10) (Lavenu et al., 1995; Winkler et al., 2005). Finally, from Late Miocene to Pleistocene basins: The Alausí - Riobamba basin. It is located at central-southern Ecuador, in the Chimborazo province (Fig. 09). This basin has a total thickness of ~ 100 m and it is filled with lahars, alluvial fan, fluvial conglomerates, and volcaniclastic rocks. Some coarse facies were deposited during synsedimentary deformation and a compressive tectonic regime (Fig 10) (Lavenu et al., 1995; Winkler et al., 2005).

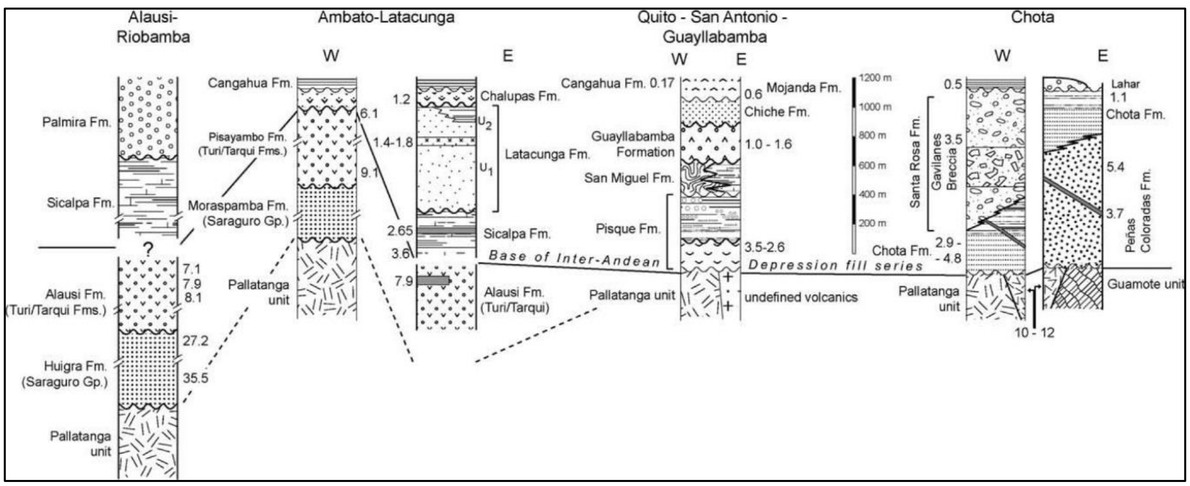

Figure 8.-[Composite stratigraphy of the Late Miocene to Pleistocene Interandean Basins of Ecuador. Numbers for the Chota basin are ZFT and AFT ages in Ma; other numbers are K/Ar and $^{40}Ar/^{39}Ar$ ages in Ma. (taken from Winkler et al., 2005).]

From Eocene to Late Miocene basins to the south of The Alausí - Riobamba basin is locating The Cuenca Basin (Fig. 09). It is the largest Neogene intermontane basin in the southern part of the Ecuadorian Andes. The basin has a total thickness of ~ 4200 m, composed of a coarsening-upward succession of lacustrine megaturbidites, fluvial and alluvial deposits (Hungerbühler et al., 1995; Marocco et al., 1995). To the South direction The Giron-Santa Isabel sub-basins (Fig. 09) contain facies deposited at sea level, which drained into the larger Cuenca basin. This basin comprises an alluvial fan and fluvial, bedload river, and shallow marine deposits (Steinmann et al., 1999). Next, The Nabón basin is located 60 km to the south of Cuenca city (Fig. 09). and is composed of Oligocene to Miocene volcanic series. It has a thickness of ~ 600m and consists of volcaniclastic breccias, fluvial-lacustrine sandstones, ignimbrites, andesitic lava flows, and metamorphic rocks from the Eastern Cordillera (Hungerbühler et al., 1995; Marocco et al., 1995). Finally, The Loja, Vilcabamba - Malacatos, and Zumba basins are located in the southern part of Ecuador (Fig. 09). These basins are composed of reworked material from volcanoes and adjacent metamorphic basement rocks (Hungerbühler et al., 1995), composed of a coarsening-upper succession of shallow marine siltstones and sandstones being overlying by conglomeratic proximal and distal alluvial fans and fluvial deposits (Toro Álava, pers. comm.).

2.4. Chota Basin

There are previous studies focused on the tectonic evolution and the stratigraphy of the Chota basin. Tibaldi & Ferrari (1992) explained that the deformation of the northern sector of the Inter Andean Valley, that originated the morphology of the Chota basin, suffered a phase of compressional deformation in the Pliocene epoch, causing cylindrical folds and reverse faults; and, after that, occurred an extensional stage in the Holocene developing pure and left-lateral normal faults. The oldest rocks in this sector comprises lacustrine and volcano-sedimentary deposits (with Pliocene andesite and Miocene continental deposits) belonging to the Chota group.

According to Egüez & Beate (1992), the Chota basin presents a complex deformation, with synsedimentary folds and faults developed in the different phases of evolution of the basin. Three main faults controlled the development of the Chota basin: the Culebrón, Cariyacu, and the Ángel faults (Fig. 11). This study proposed four stratigraphic units, from base to top: the Chota Unit, with 380 m in thickness, comprising fluviatile and lacustrine deposits like shales, conglomeratic sands, and claystones. The Santa Rosa Unit includes breccias and conglomerates with metamorphic and volcanic clasts and has 1000 m in thickness. The Peñas Coloradas has 800 m in thickness and contains conglomeratic sandstones and a transition of shales to intercalations of conglomerates and sands. Finally, at the top, the Granalotal unit, 350 m in thickness, composed of fluvial-lacustrine deposits.

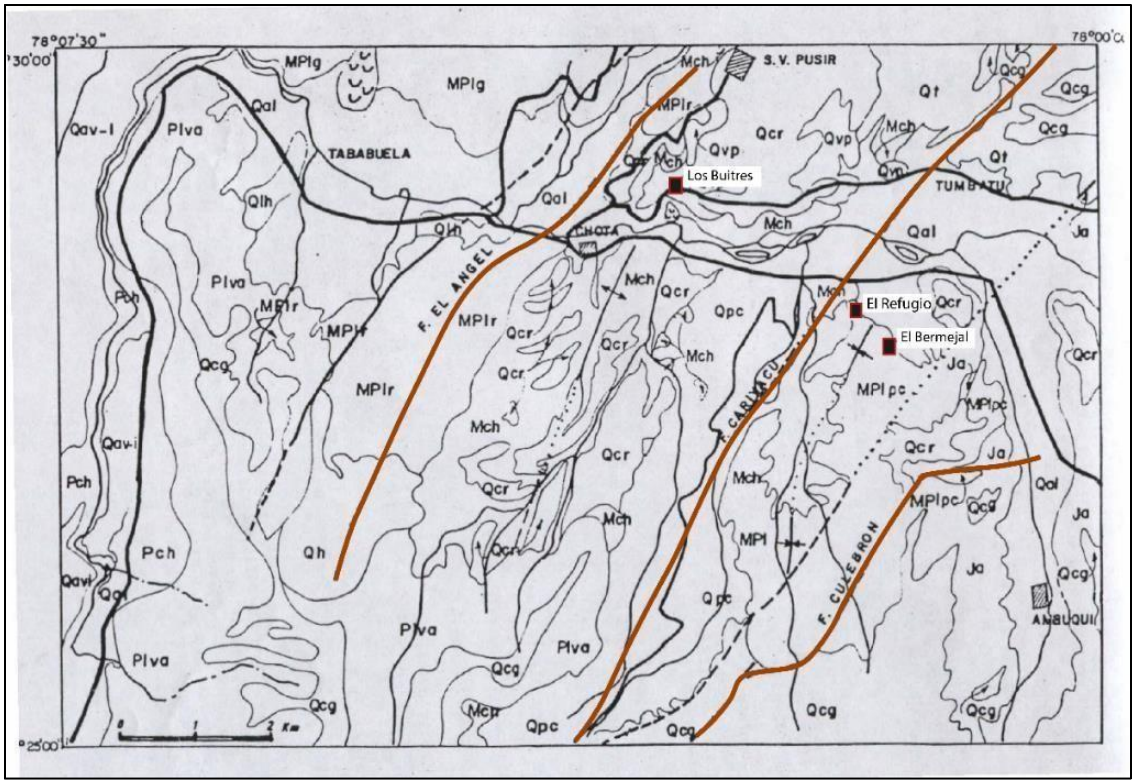

Figure 9.-[Geologic map proposed by Euguez and Beate (1992), it shows in red color lines the main faults which control the development of the Chota basin. Key: Qal, Alluvial deposits; Qcr, reworked Cangagua; Qcg, primary Cangagua; Qvp, "San Vicente de Pusir" Landslaide; Qh,"El Hondon" Landslaide; Qpc,"Pillan Chiquito" Landslaide, Qt, "Tumbatu" Landslaide; Qav-I, Imbabura volcanics; Pch, Chachimbiro volcanics; Plya, Angochagua volcanics; HPlg, Granalotal unit; MPlpc, Peñas Colorads unit; Mplr, Santa Rosa unit; Mch,Chota unit; Ja, Amburqí Metamorphics (taken and modify from Reinoso. M., 2021).]

Barragan et al. (1996) determined two stages of basin evolution in the Chota basin: The Opening, and the Closing. The basin opening is a consequence of a transtensional event that caused displacements along normal faults. These faults produced a depression that after was infilled with sediments. The Chota Fm was interpreted by Barragan et al. (1996) as a deposit formed in this stage and the change of fluvial to lacustrine environments was controlled by the velocity of tectonic subsidence. The closing of the Chota basin is characterized by a compressive tectonic regime, in a NW-SE direction, that caused dextral and inverse faults that led to the formation of marked reliefs on the western side of the basin that were recorded by the Santa Rosa unit. Later a rotation of the main compressive stress vector occurred, shifting to an East-West direction that created dextral and inverse faults that developed reliefs to the eastern margin of the basin that resulted in the deposition of Peñas Coloradas y Carpuela unit (Barragán et al., 1996). Therefore, Chota basin fill is defined by 4 units from base to top: Chota Fm located in the central part, Santa Rosa Fm. to the western margin, Peñas Coloradas Fm. and Carpuela Fm. develop to the eastern margin of the basin (Fig. 12).

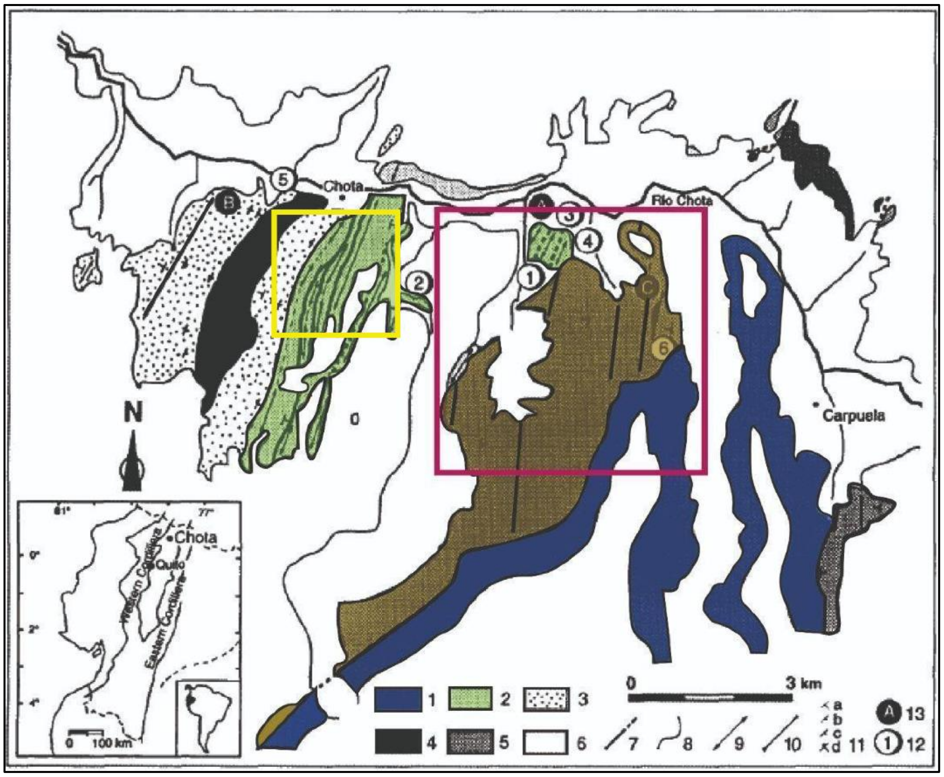

Figure 10.-[Geologic map from Barragán et al (1996) modified by Reinoso. M. (2019). Key: 1. Metamorphic basement, 2. Chota Member, 3. Santa Rosa Member, 4. Gavilanes Breccias, 5. Peñas Coloradas (brown) and Carpuela (black) Members, 6. Quaternary deposits, 7. Fault, 8. Normal contact, 9. Anticline axis, 10. Syncline axis, 11. Dipping, 12. Location of studied folds, 13. Location of studied microfractures sites. The pink square represents the study area of Reinoso. M. and Fonseca. E. (2019) Study. The yellow square represents the current study area of this research.]

The Chota Fm is interpreted like the older unit because it overlays the basement (Pallatanga Unit to the West, or Guamote Unit to the East), and also it conformably and unconformably underlies the Santa Rosa and Peñas Coloradas Fm. respectively (Fig. 10) (Barragán et al., 1996; Winkler et al., 2005). This unit has 500 m in thickness and is composed of fining-upward alluvial sequences, volcanic-conglomerate clasts, mudstones and claystones intervals. The Santa Rosa Unit to the west overlies the Chota Fm and the basement (Fig. 12). It has a ~ 1000 m in thickness and comprises metamorphic, volcanic, and sedimentary conglomerates as well as fluviatile sandstones, claystones, and siltstones deposits. The Peñas Coloradas Fm. to the East of the basin, which has a fault contact with the Ambuquí subdivision, and has an unconformable angular contact with the Chota Fm (Fig. 12). The

Peñas Coloradas unit has 600 m in thickness and comprises alluvial fan deposits, sheet flows, debris flows, and coarse volcanic deposits. The last stratigraphic unit, the youngest in the Chota basin, is the Carpuela Fm. This unit rests in a faulted contact with the metamorphic Pacheco subdivision (basement). The Carpuela Fm. has ~ 300 m in thickness and consists of coarse-grained conglomerates, and alluvial, metamorphic and volcanic deposits (Barragán et al., 1996).

Regarding the tectonic interpretation of the Chota basin, Winkler et al. (2005) proposed a ramp basin model to explain the development of the inter-Andean depression that generated different basins, including the Chota basin, which suffered shortening in a compressive regime that originated reverse faults on both margins of the basin. During this process, three units were developed in the Chota basin, with a total of approximately 1200 – 1400 m in thickness, from base to top: Peñas Coloradas, Chota, and Santa Rosa formations (Fig. 10, Fig. 13).

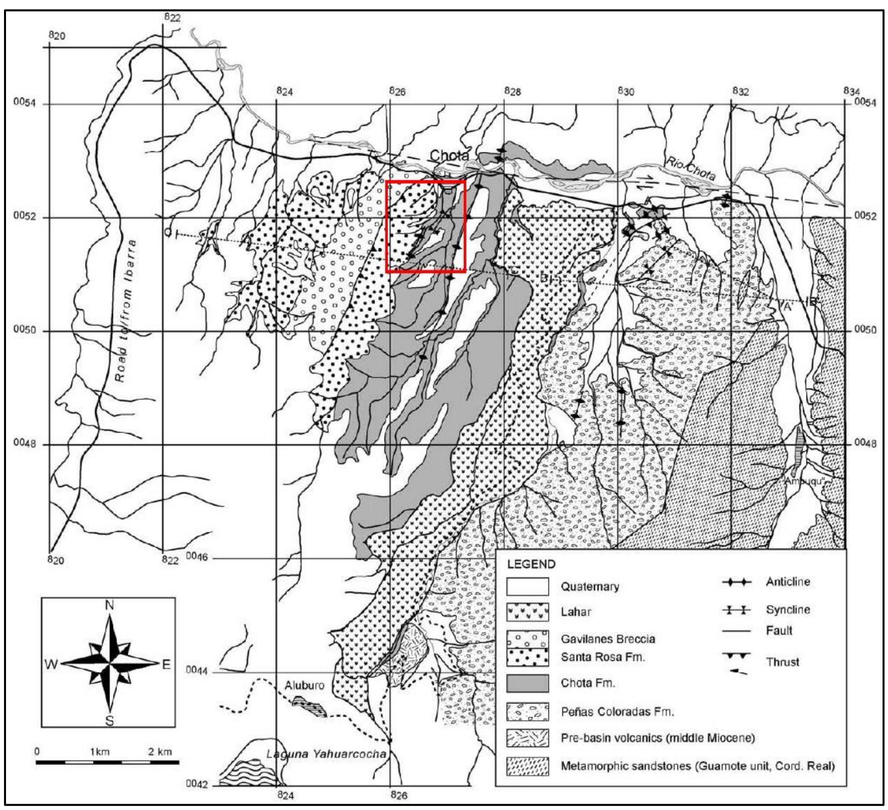

Figure 11.-[Chota basin geologic map from Winkler et al., (2005). The red square represents the current study area of this research. At the right-down there is the legend which sow more details about the map.]

According to these authors, the Peñas Coloradas Fm. was interpreted like the older unit in the basin due to a Zircon fission-track (ZFT) analysis obtaining an age of 5.4 ± 0.4 Ma; the Chota Fm. ranges in age between 4.8 ± 0.4 and 2.9 ± 1.5 Ma. (Fig. 10). Thus, the results of ZFT ages of Winkler et al. (2005) suggest that the Peñas Coloradas Formation is older than the Chota Formation. The Peñas Coloradas Fm., to the East, comprises alluvial fan conglomerates, volcaniclastic breccias, and metamorphic rocks. The Chota formation comprises volcanic, fluvial, and lacustrine deposits. And finally, The Santa Rosa Formation, to the West, consists of fluvial to alluvial fan deposits.

In the eastern part of the Chota basin, according to Fonseca. E. and Reinoso. M. (2021) in the eastern Chota basin we can identify Seven different stratigraphic units: 1. Metamorphic basement, 2. the Chota Fm, the Peñas Coloradas Fm is divided into fourth units (3. Canales Colorados member, 4. Brillosas member, 5. Tabulares member, 6. Volcanicas member), and finally, 7. Volcanicas member (Fig. 14).

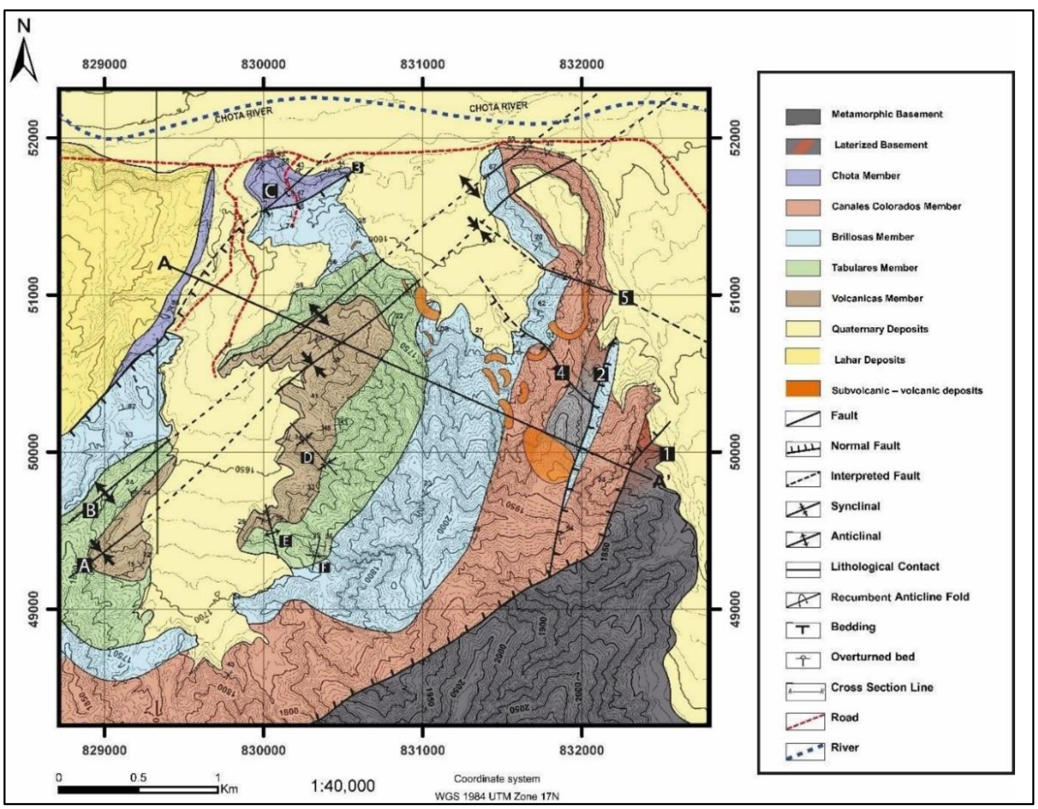

Figure 12.-[Chota basin geologic map from Reinoso, (2021). This map is focus on the East part of the Chota basin. The numbers are used to identify the faults and the letters to identify the folds. At the right part of the map there is the legend, which shows in detail the lithology and the different structures. Section A-A' represent a cross section.]

Along the Peñas Coloradas mountains, the stratigraphy is composed by: the metamorphic rocks of the Ambuquí Group being overlien by a section of 48 m in thickness of intercalations of claystones and fine to medium sandstones that transitions to the upper section to medium to coarse sandstones (Fonseca, 2021). Immediately above, and in faulted contact, appears the Peñas Coloradas Fm. composed of, from bottom to top, the Canales Colorados Mb. (128 m in thickness, with large channels of intercalations of conglomerates and sandstones with erosive contacts), the Brillosas Mb. (146 m, with high content of white micas and pumices) and the Tabulares Mb. (67 m, composed by alluvial fan conglomerates), and the Volcanicas Mb. (72 m, composed by volcanic breccias and lavas).

The present study focuses on the stratigraphic, sedimentological, lithological and mineralogical study of lacustrine and fluvial deposits the Chota Fm. in the western side of the Chota basin, northern Imbabura province, between “Loma Gavilanes” and “Loma Salada” mountains (Fig. 03) analyzing the stratigraphical and sedimentological sequences composing the West Chota Formation south direction to the Chota River.

CHAPTER 3. METHODOLOGY

To achieve the objectives proposed in this study, we employed a multi-disciplinary approach that involves six main tasks, as follows: geological mapping, sample collection, stratigraphic analysis, sedimentary analysis, sample preparation, and X-ray diffraction analysis. A geological mapping was conducted through fieldwork. During this period of fieldwork, rock outcrops, stratigraphical, sedimentological, and tectonic observations was carried out. Also, remote sensing technique played an important role in the geological mapping fieldwork using satellite imagery, aerial orthophotography, and GIS software for get advantage in areas of difficult access. Also, stratigraphic and sedimentary analysis was performed by construction of stratigraphic logs. The sedimentary rocks sampling was developed in different rock layers, an after that was treat to its post analysis. Sample collection was carried out to collect sandstones and mudstones rocks, for petrographic analysis under the microscope and X-ray diffraction analysis respectively. Also, in this study are carried lithological and mineralogical study based on its samples. Finally, the last step of analysis was to get the data from these analyses and integrate them to develop a comprehensive understanding of the geology of the study area. This information is expected to be valuable for the community in understanding the geology in the area that could be used for future geological studies.

3.1. Geological Mapping

Consist of conducting fieldwork and virtual observations employing remote sensing techniques, such as satellite imagery, aerial orthophotography, and GIS software. Virtual observations were carried out in ArcMap and Google Earth software focusing on the western side of the Chota Basin; at the occurrence area of the Chota Unit. This activity lasted approximately one month. This mapping activity was followed by fieldwork, carried out in the same place, but following the streams and rivers and climbing the mountains. The fieldwork duration was approximately three months. With the collected data, local stratigraphic logs were developed to characterize facies and environments and determine stratigraphic correlations and bedding attitudes. A low-detailed map of the study area summarizes the information.

Moreover, during the geological mapping activity, a 1:5000 geologic map was performed based upon a topographic base map, employing a Universal Transversal Mercator (UTM) 17N zone projection. Also, contour line intervals were defined every 5 m and every 25 m constructed in ArcMap using a 3 m resolution Digital Elevation Model (DEM) taken from online data of the department of agriculture in Ecuador. The Map was based on orthophotos features and were upgraded with the landscape features of fieldwork job.

3.2. Stratigraphic Analysis

It involves the study of rock layers, their sequences, and their relationship to one another. In this project, the stratigraphic analysis was conducted to document the different sedimentary rocks studying rock outcrops, understanding the occurrence of facies, the paleo-environment in which they formed, and the sequence of events that occurred in the West Chota Fm. During the field mapping period, hundreds of meters of detailed sedimentary stratigraphic columns (graphic logs) were recorded at a 1:50 scale focusing on the texture and sedimentary features to characterize the Chota Unit and its members.

The stratigraphic log construction was based on parameters such as: layer thickness, color of the beds and sediments, bedding contacts, structural data, textural parameters for clastic and calcareous sediments (grain size using the Wentworth scale for clastic sediments, and Dunham's facies for calcareous rocks), primary and secondary sedimentary structures, textural attributes of sediments and beds (grain sorting, grain roundness, and grain angularity), and other complimentary information (Fig. 15).

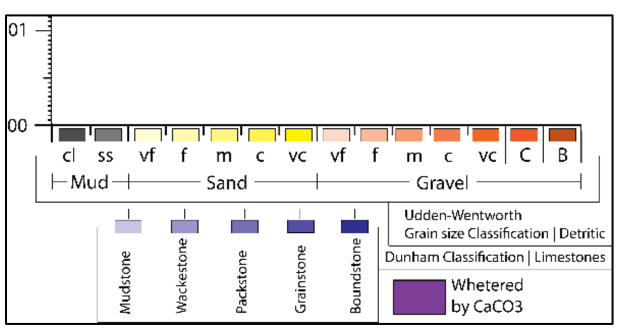

Figure 13.-[Base template for record stratigraphic log used in the study. Modified by Humanante. M. (2024). Base template is a merge between the Udden-Wentworth grain size classification for detritic rocks and the Dunham classification for limestones rocks. Key: cl, claystone; ss, siltstone; vf, very fine; f, fine; m, medium; c, coarse; vc, very coarse; C, Cobble; B, Boulder.]

The outcrops of the study area in the majority of cases were well exposed (Fig. 16). However, is recommended exploring the zone around the stream rivers looking for recent outcrops. Important remainder is that there were outcrops in which a rock pick hammer was not enough and a shovel was necessary to remove the Anthropocene cover of sediments. After the construction of stratigraphic logs, we were able to determine the different sedimentary facies present in the area, which provide valuable information on the depositional paleo-environment. In this study, stratigraphic log digitization was performed using the Adobe Illustrator software (version 26.0, Adobe Systems Incorporated, San Jose, CA, USA).

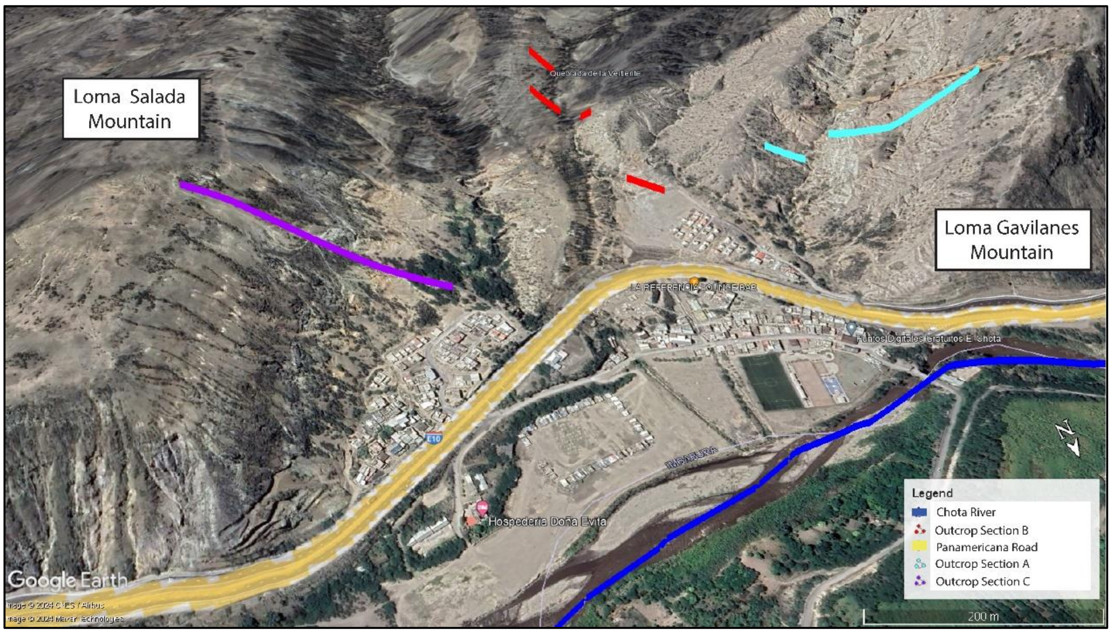

Figure 14.-[Figure show the West Chota Formation area between "Loma Gavilanes" and "Loma Salada" mountains. Outcrop Section A, Outcrop Section B, and Outcrop Section C represents examples of the outcrop distribution in the study area. Blue line represents the Chota river. Yellow line represents E35 "Panamericana" road. At the right-bottom of the figure there is the legend and over it the north direction.]

3.3. Sample Collection

In the sample collection stage, samples were collected from different locations in the study area. This activity was carried up during fieldwork simultaneously with the graphic log creation. These samples were employed for sedimentary and petrographic analysis, allowing us to understand the lithological and mineralogical composition of rocks and the depositional environment and its precedence. The sampling procedure involves collecting a set of 20 sandstones and 20 clay samples from various layers in different outcrops. The procedure of sampling was by hammering outcrops with a 33-cm long Estwing Rip Claw Solid Steel Rock Pick (hammer) (Fig. 17.A) into the rock face. If possible, I took samples about 30 cm deep from the sampled surface. The sample tools were cleaned between each use to prevent cross-contamination. After collecting the samples in a plastic bag (Fig. 17.B.b), they were labeled, cataloged, and packed carefully in a synthetic bag (Fig. 17.B.a) for transportation to the Laboratory. During the packing process, the samples were handled with care and transported in a suitcase (Fig. 17.B.a) to prevent contamination or damage during transport. The samples were stored in an appropriate environment (cool and dry place) until the analysis. Overall, sample collection is a critical step in geological research and can significantly impact the accuracy of the results.

Figure 15.-[A) Picture of a hammer 33-cm long Estwing Rip Claw Solid Steel Rock Pick. B.a) Black suitcase for rock transportation at the left. At the right-down synthetic bags. B.b) Plastic bags.]

On the one hand, sandstone samples were collected for stereoscopic analysis, examining the sandy samples collected in the field to determine their textures and structures. By determining the lithological and mineralogical composition, this analysis helps us to understand the sedimentary environment in which the sandstone was formed and its provenance. On the other hand, clay samples were collected for X-ray diffraction analysis, which in our case, was a method of determining the clay minerals abundance of rock. The clay minerals in sedimentary rocks were beneficial in reconstructing the depositional environment, and paleoclimate.

3.4. Sedimentary Analysis

The analysis involved the description of sandstones, collected during the fieldwork, employing a stereoscopic binocular microscope. This process is based on the description and observation of samples through a magnification microscope due to the increasing visual field view of the rock. This method provided detailed information on the sedimentary structures and textures, including grain size, shape, sorting, and rounding. Additionally, a highly detailed examination of sandy sediments was carried out, looking for lithological and mineral composition, texture, fabric, and diagenesis, to obtain its petrographic information. Finally, the last step was to analyze the fossil content of samples, which contribute to determine their age and the environmental conditions during deposition. Fossils can also provide information on the evolution of life on Earth and the history of the study area.

The applied workflow for the characterization of sandstones started by cutting the sandy samples into regular cubes. Samples were cut using a Rock Cutting Machine “Precision Saw, series 090500” (Fig. 18.A) in the Thin Sections Laboratory, of the School of Earth Sciences, Energy and Environment, at Yachay Tech University. Sediments were analyzed in the Nano-micro Analysis Laboratory of the School of Earth Sciences, Energy, and Environment at Yachay Tech University. Once we have the regular cube of the rock (Fig. 18.B), we hit and scratch the rock using a knife to remove sediments carefully. Sediments left due to the gravity effect and were saved into an agate mortar. The following step was a sling grind of the sediment using the agate mortar and a pestle agate with rubber coating to conserve the shape of grains (Fig. 18.C). After it, we put samples on a millimetric sheet to characterize under a binocular stereoscope. We use a binocular stereoscope “OLYMPUS SZX16 of 1X lenses” (Fig. 18.D) and a binocular stereoscope, “OLYMPUS SZ61” (Fig. 18.E) to describe sediments. The work time spent on the laboratory analysis lasted three weeks. After running all processes of sedimentary analysis, we saved and labeled sediment samples in little plastic bags for its storage.

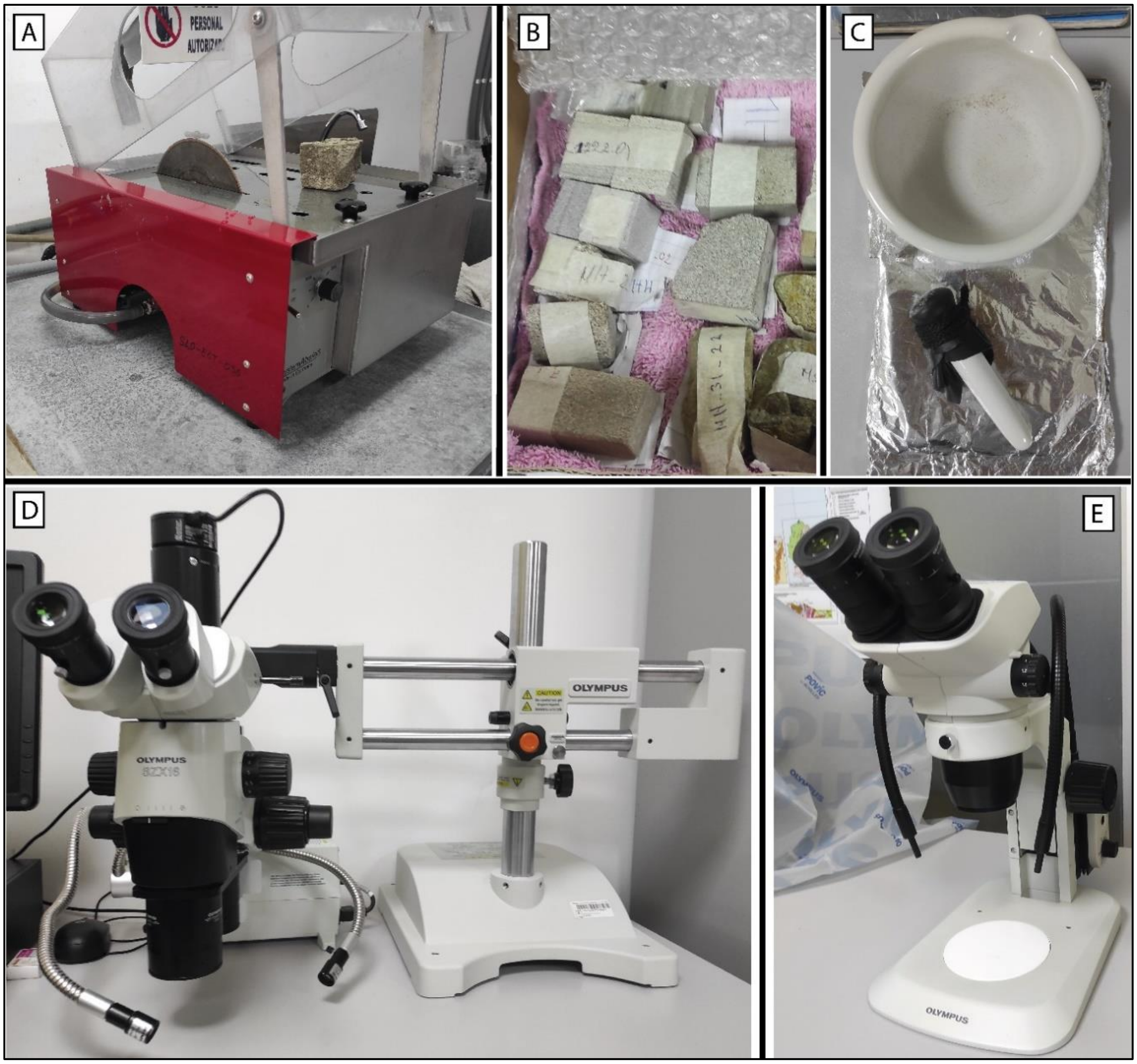

Figure 16.-[A) Rock Cutting Machine "Precision Saw, series 090500". B) Rock samples in a cube shape status. C) Agate mortar (top) and a pestle agate with rubber coating (bot). D) Binocular stereoscope "OLYMPUS SZX16 of 1X lenses". E) Binocular stereoscope, "OLYMPUS SZ61".]

3.5. X-Ray Diffraction Analysis

X-Ray Diffraction (XRD) analysis is a laboratory technique used to identify and quantify the mineral composition of a rock sample (Huff & Reynolds, 1990). The process was focused on clay samples, and it involved exposing the sample, at different angles, to a beam of X-rays, which are diffracted by the sample's crystalline structure. The resulting diffraction pattern provides information about the sample's mineral composition. To perform XRD analysis, first, we carried out first an X-Ray sample preparation method. We needed to process claystone rock samples and clay sediment samples transformed into powder, and it is due to the X-Ray Machine being able to process only fine powder sediments. The essential feature of the diffraction of waves of any wavelength is that the distance between scattering centers be about the same as the wavelength of the waves being scattered, where the wavelength of X-rays and the structural spacing of crystals both have dimensions about 10-8 cm (= 1 Å) (Moore and Reynolds, 1997). Once we had the samples correctly prepared for the analysis, the second step was to mount them and run them in the X-Ray Machine to generate the spectrum of data once the beam of X-rays acts on the sample's surface while rotating gradually. Finally, the third step was to save the data and develop a diffractogram pattern by using a specific software.

3.5.1. X-Ray Diffraction Sample Preparation

The collected claystone samples from fieldwork followed several steps until they were ready for X-Ray Diffraction Pattern Generation. First, it is necessary to store samples in beakers and weigh them to know the weight of the rock before drying. For this step, I used a Ohaus Pioneer weigh machine (Fig. 19.A). The second step was the dry process of samples; for that rock samples were dried at 80º Celsius for 24 hours using a "Drying Stove brand POL-EKO model SLW 115 STD" (Fig. 19.B, Fig 19.C), available at the Chemistry Laboratory of the School of Chemical Sciences and Engineering, at Yachay Tech University. The third step was to weigh dry samples to verify how much water was released from the claystone samples.

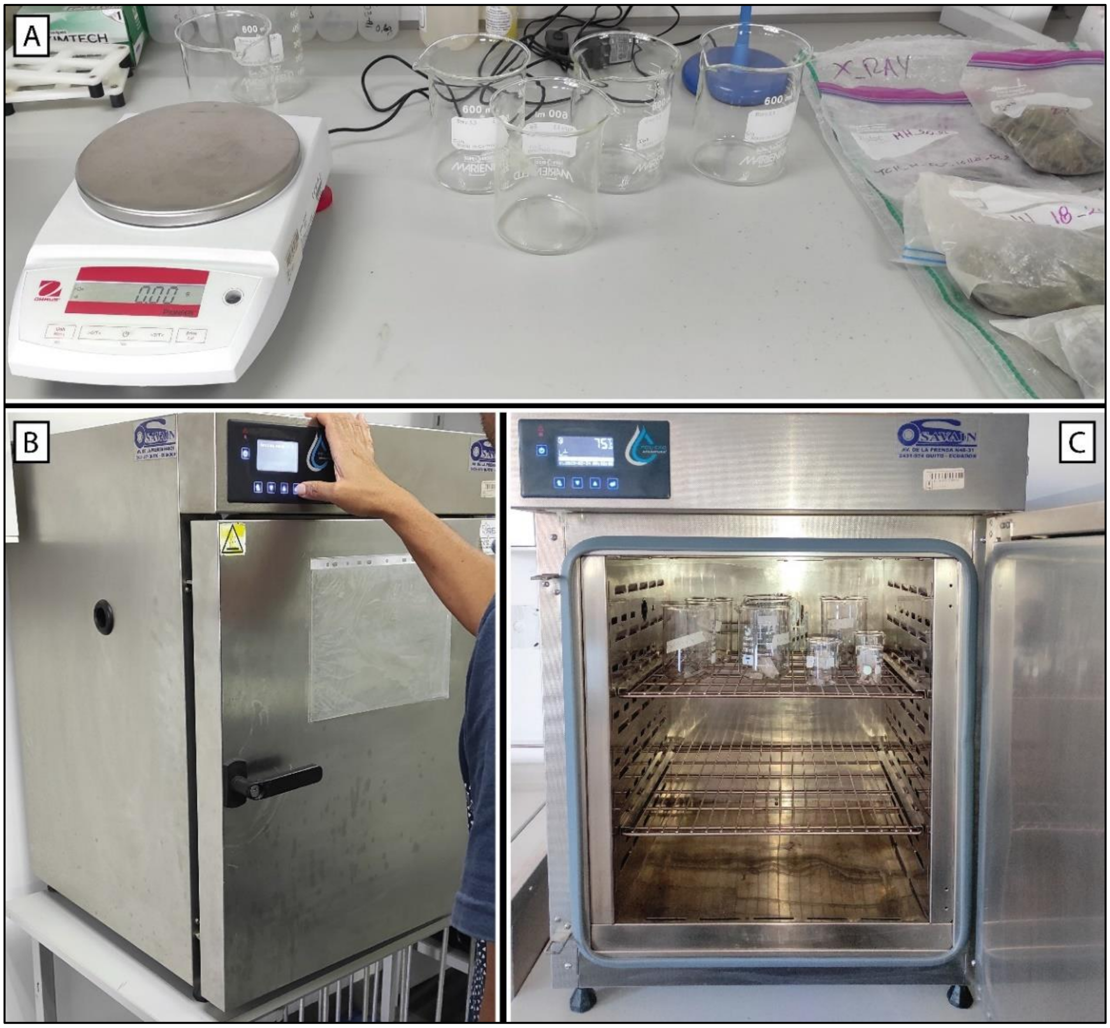

Figure 17.-[A) Rock samples in a plastic bag at the right. Beakers at the middle. Finally, at the left a Ohaus Pioneer weigh machine. B) Drying Stove brand POL-EKO model SLW 115 STD. C) Drying Stove with weighed mud samples in beakers).]

The fourth and following steps in this sample preparation were carried out at the Rock Preparation and Crushing Laboratory of the School of Earth, Energy and Environmental Sciences, at Yachay Tech University. Before to star working on the Rock Preparation and Crushing Laboratory, is necessity to equip ourself with security equipment. It is necessary to carry the experimental work with less risk (Fig. 20.A). It is important to consider that, as a routine practice, it is necessary to clean up each equipment or machine before running the sample. This method of cleaning is used to prevent cross-contamination, cleaning method is based on a vacuuming up the remaining particle (Fig. 20.B), follow by a brush cleaning. The next step is 70% alcohol cloth applications. Finally, is necessary a check cleaning using a compressed air (Fig. 20.C).

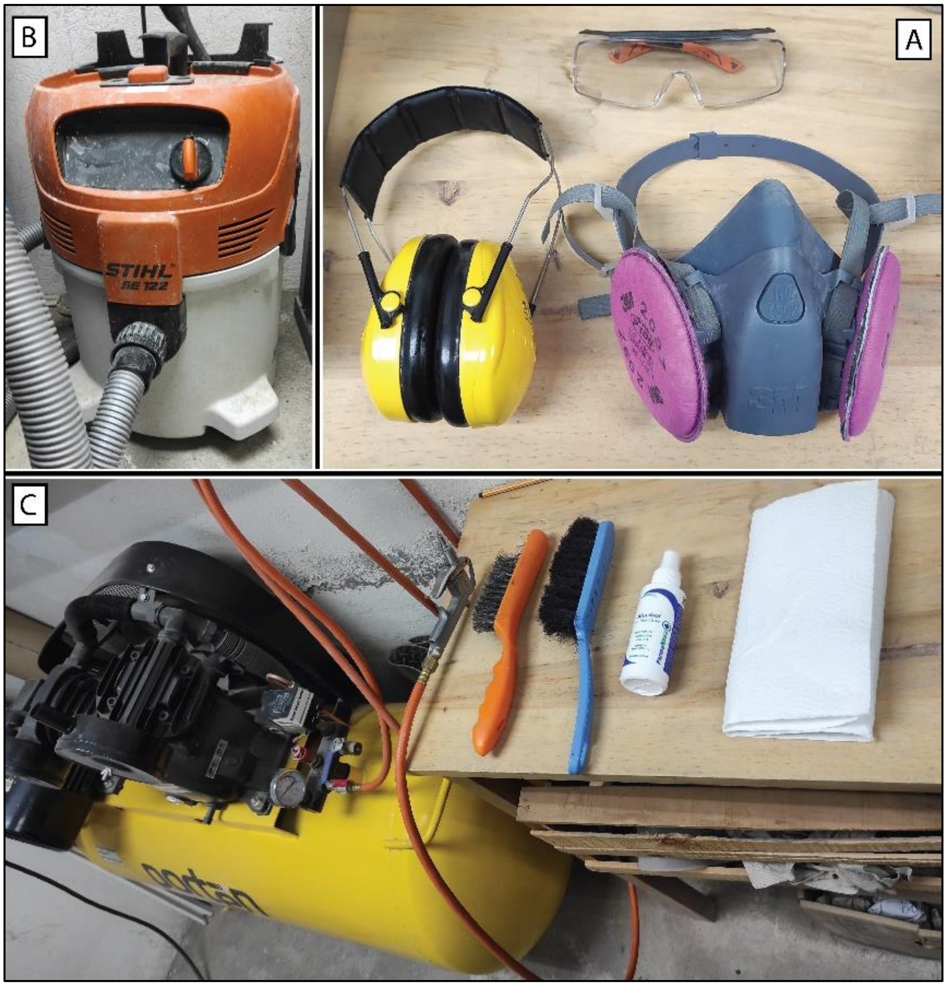

Figure 18.-[A) Protection equipment used in the Rock Preparation and Crushing Laboratory. At the top there is a safety googles glasses, at the bot right there is a dust filter mask, and to the left side there is an Anti-noise headphone. B) Vacuum cleaner machine employed in the cleaning processes. C) From left to right: A yellow-black compressed air. Orange brush with metal bristles. Blue brush with soft bristles. 70% alcohol (white). Paper cloths.]

The fourth step consisted of crushing samples, using a "Jaw Crusher, powered by an AC Motor speed control USMA24D, Model U9533" (Fig. 21.A), to reduce the grain size of the rock to a pebble size (Fig. 21.B). Step Five was grinding the sample by using a "UA V-Belt Driven Pulverizer, BICO model 242-53X2S (2 hp, 1ph, 110/220v, 60 Hz)" (Fig. 21.C) to get a fine powder. The sixth step was using a "230 MESH Sieve made on steel" (Fig. 21.D) to get lower-size grain powder. Finally, the seventh step was to save and label the samples in little plastic bags (Fig. 21.E) to store in a cold and dark environment until running the X-Ray Diffraction Pattern Generation. After this step the sample is ready to run on the "Rigaku Miniflex-600" model X-ray Diffraction Machine available at the Laboratory of the School of Chemical Sciences and Engineering, Yachay Tech University (Fig. 22.A).

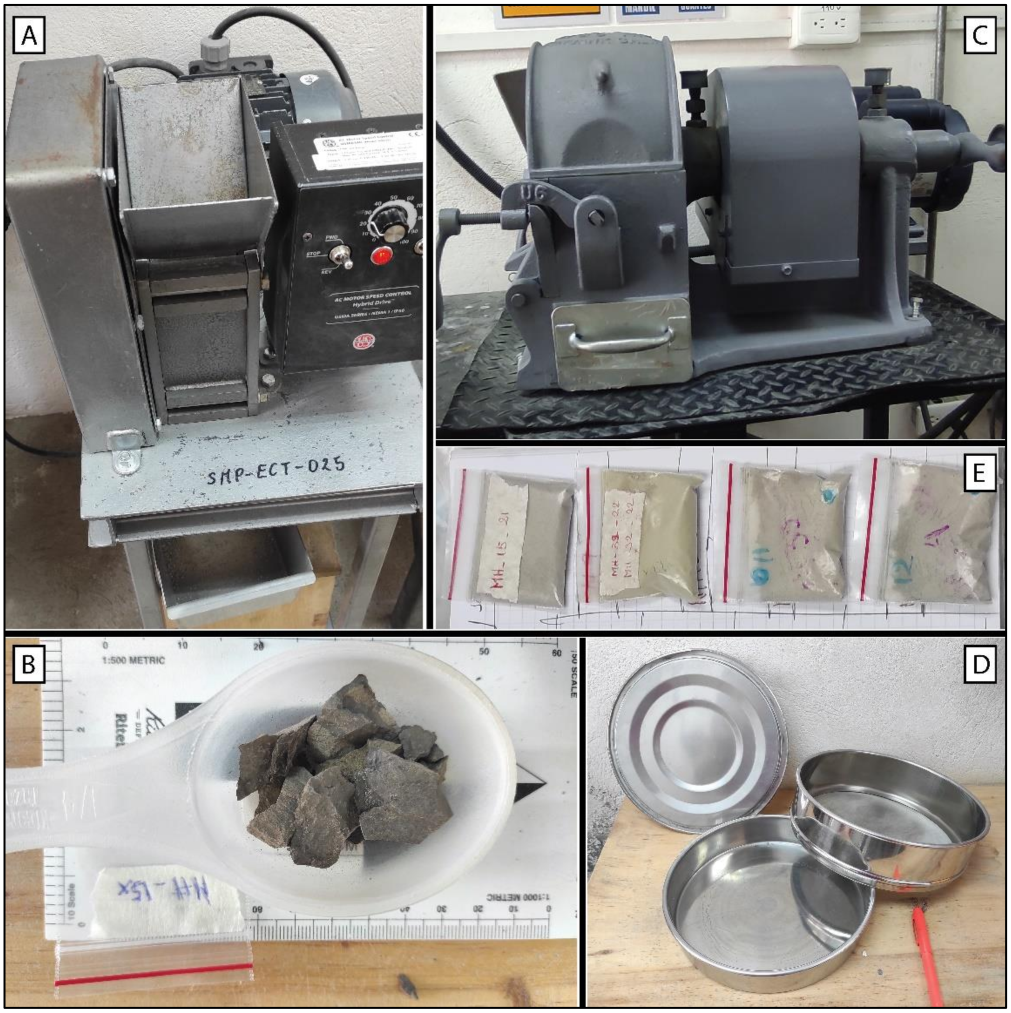

Figure 19.-[A) Jaw Crusher, powered by an AC Motor speed control USMA24D, Model U9533. B) Rock fragments of a pebble size. C) UA V-Belt Driven Pulverizer, BICO model 242-53X2S (2 hp, 1ph, 110/220v, 60 Hz). D) 230 MESH Sieve made on steel. E) Finely ground sieved samples in little plastic bags).]

3.5.2. X-Ray Diffraction Pattern Generation

Diffraction analysis was carried out by X-ray diffractometer "Rigaku Mini-flex-600" (Fig. 22.A) for polycrystalline samples, equipped with: a 600 W X-Ray tube, a Bragg-Brentano goniometer with 8-position autosampler (Fig. 22.B), and D/teX Ultra detector. It is located at the Chemistry Laboratory of Characterization of materials, of the School of Chemical Sciences and Engineering, at Yachay Tech University. The following steps were necessary to carry out for the diffractogram pattern generation. First, the sample must be finely ground and homogenized to obtain representative and uniform values (Fig. 22.C). The second step is to put the sample in an Aluminum sample holder, with 8 positions. To carry out the task the Sample Holder Kit is used (Fig. 22.D and Fig. 22.E). The third step was to mount the aluminum holder with samples on the "Rigaku Mini-flex-600". The fourth step was to shoot the samples with X-rays while being rotated and tilted at different angles of X-ray scattering to ensure the X-rays interacted with the entire sample volume.

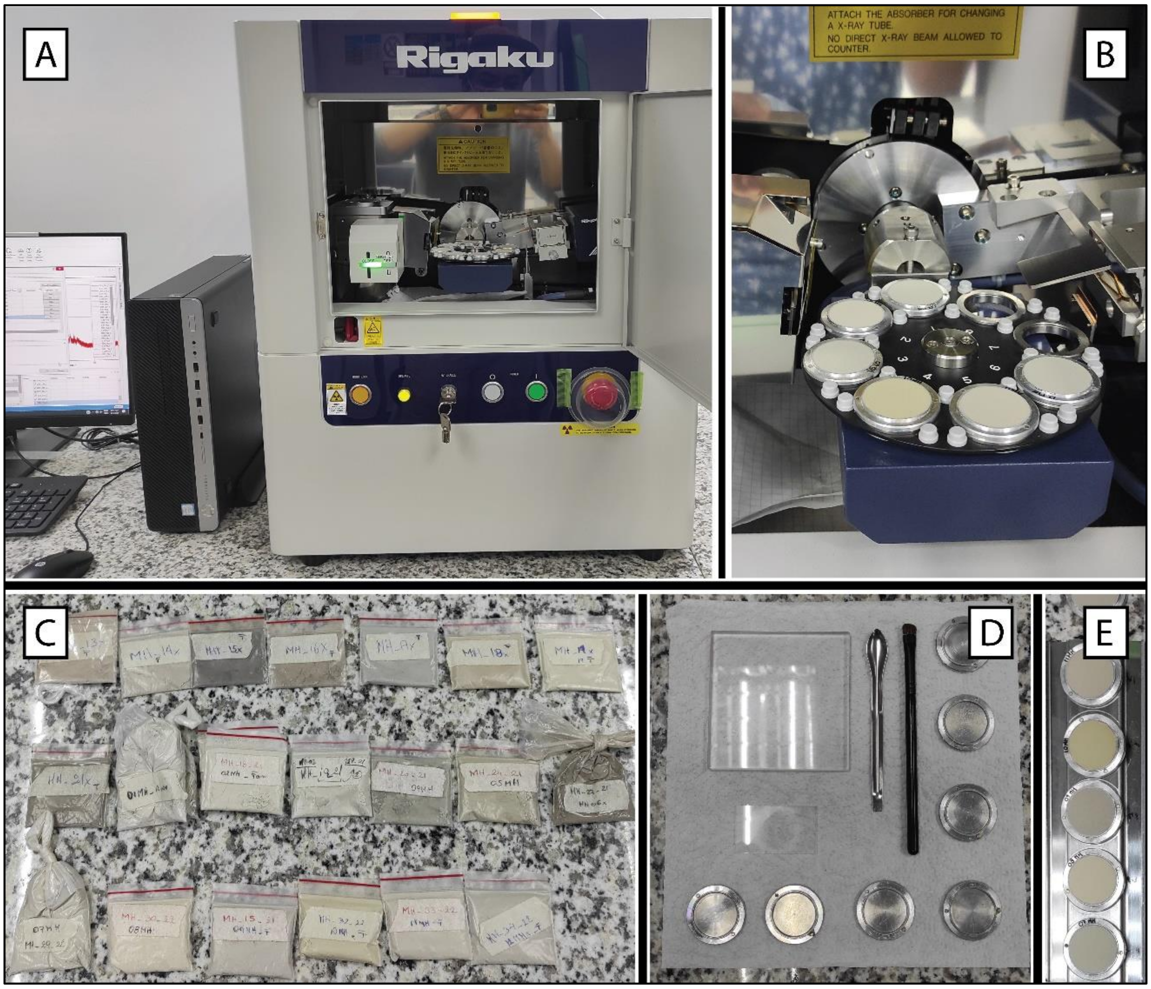

Figure 20.-[A) Rigaku Miniflex-600. B) Bragg-Brentano goniometer 8-position autosampler with six position filled by clay size grain sample. C) Clay size grain sieved samples in little plastic bags. D) Sample Holder Kit composed by: Planar glasses. Aluminum spoon (gray), Paintbrush (black). Aluminum Sample Holder (gray). E) Mud samples at clay size grain filled in Aluminum Sample Holders.]

The measurement conditions were: X-ray generator operated at 40 kV and 15 mA, CuK(alpha) radiation source (sealed tube), a Theta/2Theta scanning axis was used for data collection, step width of 0.005°, scanning range of 3° - 140° in 2 Theta, and D/tex Ultra2 detector in 1D scanning mode. The diffracted X-rays are collected on a detector, which records the intensity and angle of diffraction of the X-rays. The fifth step was to collect the data by using "Match!" Phase Analysis, using Powder Diffraction Software (version 3.15

build 258 for Windows 64-bit, Putz Holger, 2003-2023, Crystal Impact, Bonn, Germany), which analyzes and determines the diffraction pattern to the crystal structure and composition of the samples. The final step was to analyze the resulting data. In this case, the resulting diffraction pattern can be compared to reference patterns in databases to identify the mineral phases present within the analyzed samples. The crystallography open database match (COD-Inorg 2022.11.07) was used as a reference pattern. However, this method did not yield matching clay minerals, so manual searching was developed for each sample to determine the signal corresponding to the main clay minerals at the American Mineralogist Crystal Structure Database.

3.6. Petrographic Analysis

For the identification of sedimentary rock types in the field, two principal features to note are: composition-mineralogy and the grain size. On the basis of origin, sedimentary rocks can be grouped into four categories: Terrigenous (sandstones, mudstones, conglomerates and breccias), biochemical - organic deposits (limestones, dolomites, coal, phosphorites and cherts), chemical (ironstones and evaporites), and volcaniclastics (tephra, tufts) (Tucker, 2003). Sandstones are composed of five principal ingredients: rock fragments (lithic grains), quartz grains, feldspar grains, matrix and cement. The composition of sandstones is largely a reflection of the geology and climate of the source area. Minerals, in decreasing order of stability, are: quartz, muscovite, microcline, orthoclase, plagioclase, hornblende, biotite, pyroxene and olivine. The accepted classification of sandstones is based on the percentages of Quartz + chert (Q), Feldspar (F), Rock fragments or lithics (L), and Matrix. Then, the composition of a sandstone is based on a modal analysis determined from the thin-section of the rock using a petrological microscope and a point counter. Those samples with a matrix content lower than 15% are classified as arenites, and those with more than 15% of matrix content are classified as wackes (Tucker, 2003).

Considering the sandy sediments composing the clastic sediments within the Chota Units, and its three members, are demi-consolidated, and containing high proportion of clayey and silty matrix, the procedure for the thin section preparation was not optimum because, once the skirl of rock was cut, the sandy sample started to be peeled, not being able to be optimally mounted on a glass porta slides nor for being polished and reduced the rock cut until attaining 30 microns in thickness, the appropriated thickened for a standard thin section analysis under the petrographic microscope. After several failed attempts for thin section preparation, we decided to run the petrographic analysis on sandy sediments from the Chota Unit employing samples seen under the binocular microscope.

3.6.1. Petrographic Analysis Under Binocular Stereoscope

Once the rock sample was cut employing the Rock Cutting Machine "Precision Saw, series 090500" (Figure 18.A.) installed in the Sample Preparation Laboratory, of the ECTEA, Yachay Tech University, the cubic sample was dry for 8 hours in an oven at 80 ºC. After being dry, 1 cc of the sandy sediments left due to the gravity effect and were saved into an agate mortar. The method employing for this process was: hit and scratch the rock using a knife to remove sediments carefully. Next step was a sling grind process of the sediment using the agate mortar and the agate pestle with rubber coating to conserve the shape of grains (Fig. 18.C). The composition of the sandy grains was analyzed based upon the crystallographic properties of crystals (crystalline system, color, habit, alteration), texture, and the matrix content. The analysis was carried out under a binocular stereoscope "OLYMPUS SZX16 of 1X lenses" (Fig. 18.D) and by a binocular stereoscope, "OLYMPUS SZ61" (Fig. 18.E) located at the Nano-micro Analysis Laboratory of the School of Earth Sciences, Energy and Environment, at Yachay Tech University,

Once the full sample was analyzed, and counted the relative proportion of occurrence of minerals, a bar diagram was constructed for representing the occurrence of minerals in each sample (Fig. 23.A). After that, the modal analysis was executed for constructing the QFL database and its representation in normalized triangular diagrams with specific fields of classification with: quartz arenites, arkoses, litharenites, greywackes, etc. (Fig. 23.B). In this way, the classification of sandy samples was carried out, contributing to the interpretation of the precedence of these sediments.

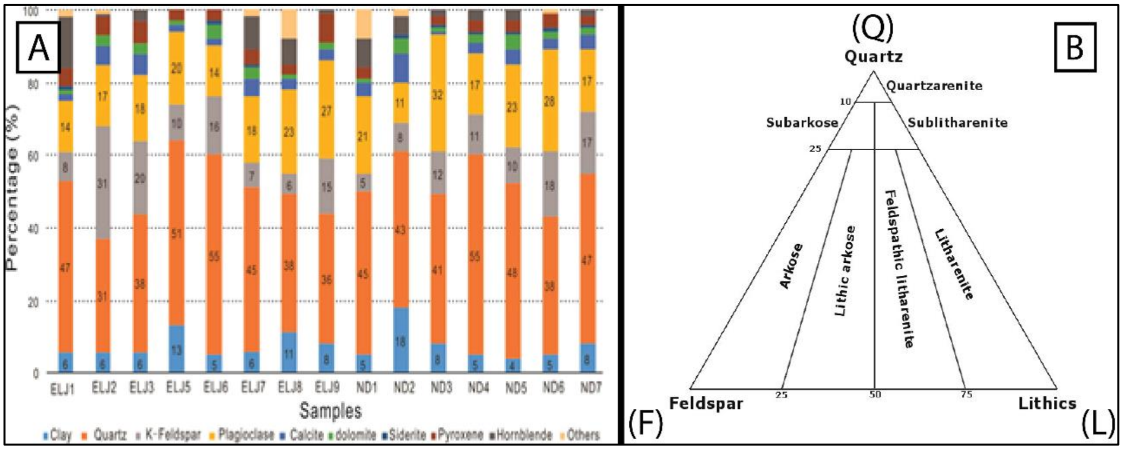

Figure 21.-[A) Bar diagram expressing the total occurrence of minerals under the microscope (source: Tao et al., 2021). B) Classification of arenites and greywackes. Basic triangular diagram for the classification of sandstones (source: Folk, 1968, 1980).]

3.7. Data Integration

This item entails merging all the information gathered from the various analyses executed with this purpose to create a thorough picture of the geology of the studied area. This stage was crucial for the description, understanding and interpretation of the region and for determining the geological processes sculpting the Chota stratigraphic unit in the study area.

CHAPTER 4. RESULTS

An intrusive dike and five subunits were identified between “Loma Gavilanes” and “Loma Salada” mountains. In the West Chota Fm was possible to identify three members outcropping from west to east and from bottom to top, as follows: (1) Lower Chota Member: at the base, outcropping immediately east to the Loma Gavilanes; (2) the Middle Chota Member: in the middle part of this stratigraphic unit, outcropping to the east of the Lower Chota Member towards the East, but west of the Loma Salada mountain; and (3) the Upper Chota Member: outcropping immediately to the West of the Loma Salada and in continuity to the East of the Middle Chota Member. (Fig. 24); and additionally, was possible to identify youngest, Alluvial Fan Deposits and Fluvial Terrace subunits.

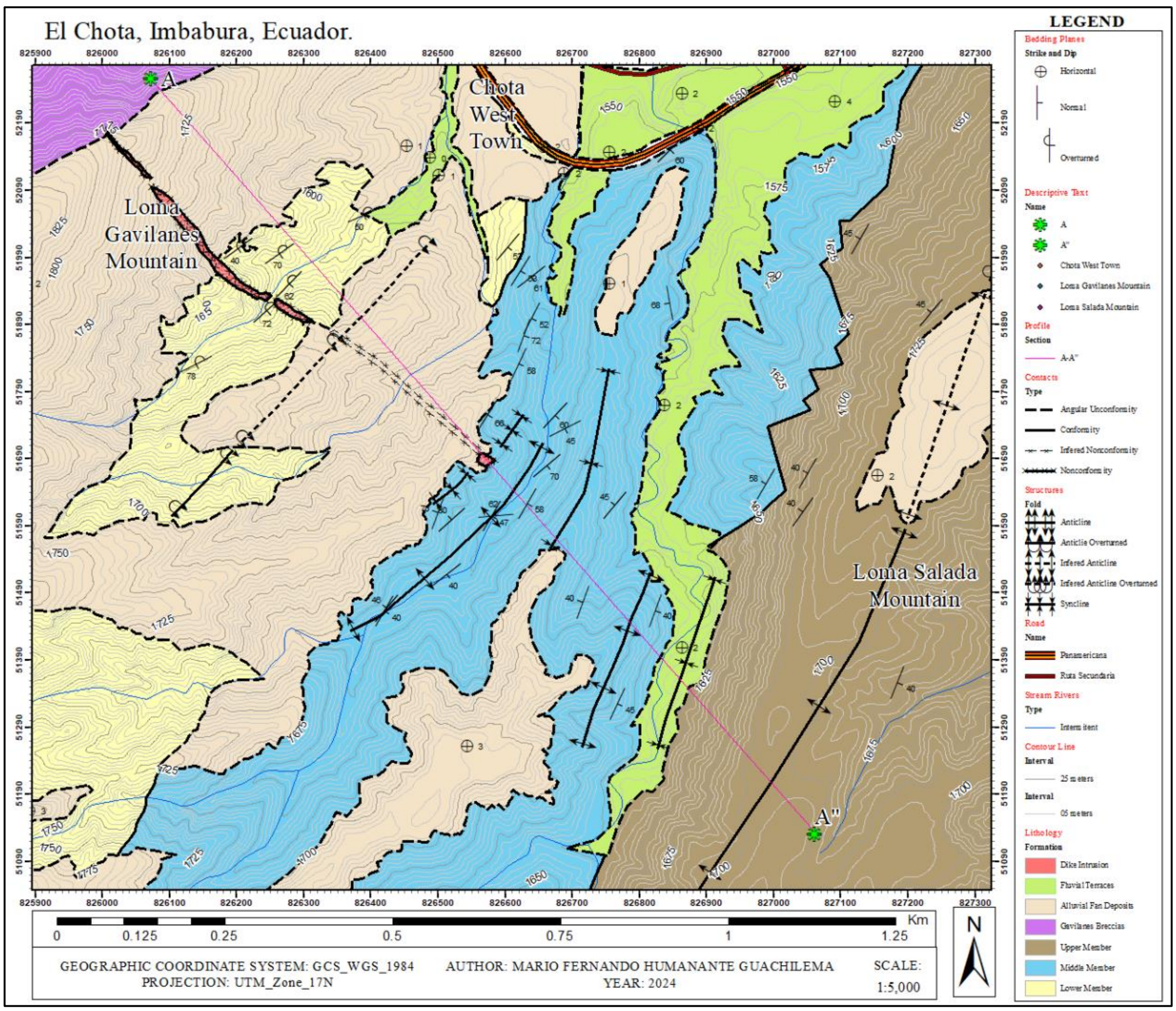

Figure 22.[Geologic map of the West Chota Formation area with principal geological structures. Map shows the different members identified. At the right-side legend explain more details.]

4.1. Stratigraphic Results

Six stratigraphic sections of nearly 300-meters in thickness, from 2 members of the West Chota Fm, were described in detail creating 1:50 scale graphics logs perpendicular to the bedding. The sections covered and described are the Lower Chota Member and the Middle Chota member. The stratigraphy of the Lower Chota Member (Fig. 24) starts with the Section No. 01 (Fig. 24. D and Fig. 24. C), at the bottom. Follow by Section No. 02 (Fig. 24. B). Next by Section No. 03 (Fig. 24. A). It finishes with the Section 04 (Fig. 24. E), which starts at the transition from the Lower to the Middle Chota Member. The Middle Chota Mb (Fig. 23), composed by two sections of cream to gray and brown in color, composed of fining-upper sandstones and siltstones, fossiliferous mudstones, and claystones with limestones at the top of the member. Moreover, the Upper Chota Mb., composed of multi-colored gray, pink, cream, and brown, coarsening-upper, claystones and siltstones, was studied only in low detail. The studies areas of Upper Chota member were carried out at the lower and upper part of the "Loma Salada" mountain because of its significant thickness and slope in the field, however the lack of time make difficult to perform a stratigraphy log of this member.

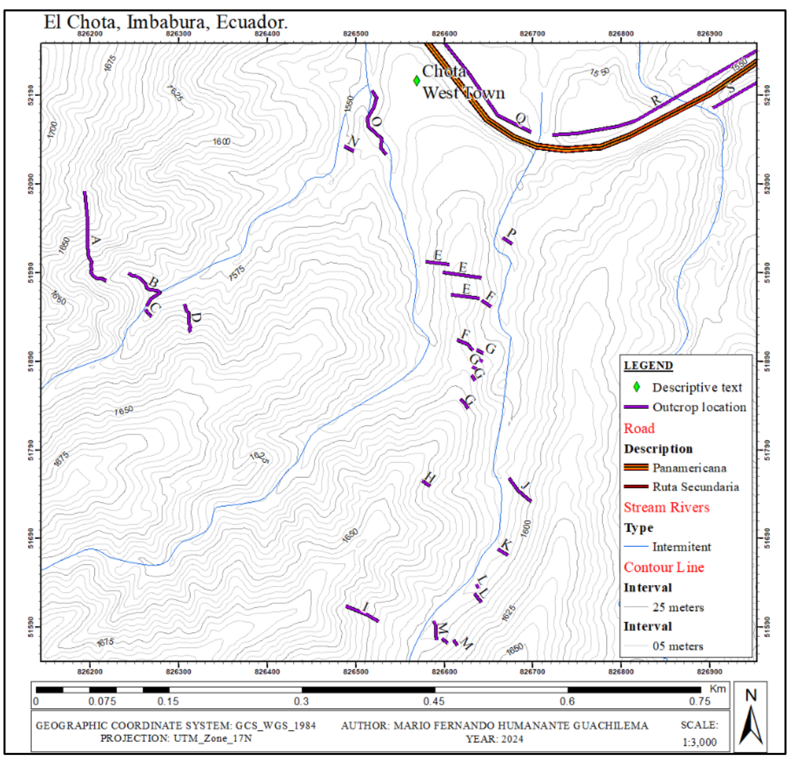

Figure 23.-[Map Location of Outcrops. Map in 1:3000 scale showing in purple the location of the graphic logs created for the sedimentological and provenance analysis of the West Chota Formation in the Chota basin. Letters over the outcrops indicate the name of it. To the right "Loma Salada" and to the left "Loma Gavilanes" mountains. At the North part of the map, near to the "Panamericana" road, there is the West Chota Town. Finally, legend located at the right-bot side.]

4.1.1. Lower Chota Member

From bot to top, the Lower Chota Member section was constructed through outcrop D, outcrop C, outcrop B, and outcrop A (Fig. 25 and Fig. 26). It is located southwest of the Chota West Town. The total recorder section presented for the stratigraphy of Lower Chota Member has a thickness of 106 meters (Fig. 26). From bottom to top, the first 10 meters of the section is represented by tabular sandstone layers with the presence of mudstones and pebble grained conglomerates with the basal erosive surface (at the middle). Over this section, there is a 20-meter thickness represented by tabular intercalation of mudstones with sandstones and pebble conglomerates with the basal erosive surface. The following 10 meters are conformed by an intercalation of tabular sandstones with pebble conglomerates (at the bottom) and channelized pebble conglomerates with basal erosive surface (at the top). The following 20 matters of the section are conformed, from bottom to top, for channelized pebble conglomerates with the basal erosive surface, overlaid by tabular sandstones followed by intercalation of tabular mudstones and sandstones. Over it, there are 10 meters of tabular pebble conglomerates with basal erosive surface, followed by a tabular mudstone layer overlayed by tabular sandstones. The following 10 meters are conformed for tabular volcanoclastic sandstones (at the bottom) and intercalations of tabular sandstones with laminated mudstones (at the top). The next 10 meters are conformed by an intercalation of sandstones with mudstones, followed by tabular pebble conglomerates with basal erosive surface, which is overlayed for tabular sandstones. Finally, 16 meters are conformed by tabular sandstones (at the bottom) overlayed by cobble conglomerates with the basal erosive surface (at the top); in this final section, there is a volcanic igneous intrusion (Annex 01. Fig. 46) crossing the top of the sandstones and all the conglomerate layers. For this study I focus the analysis description on four sections of the Lower Chota Member (Fig. 26). From bottom to top: Section N° 1 (Fig. 27), Section N° 2 (Fig. 28), Section N° 3 (Figure 29), and Section N° 4 (Figure 30).

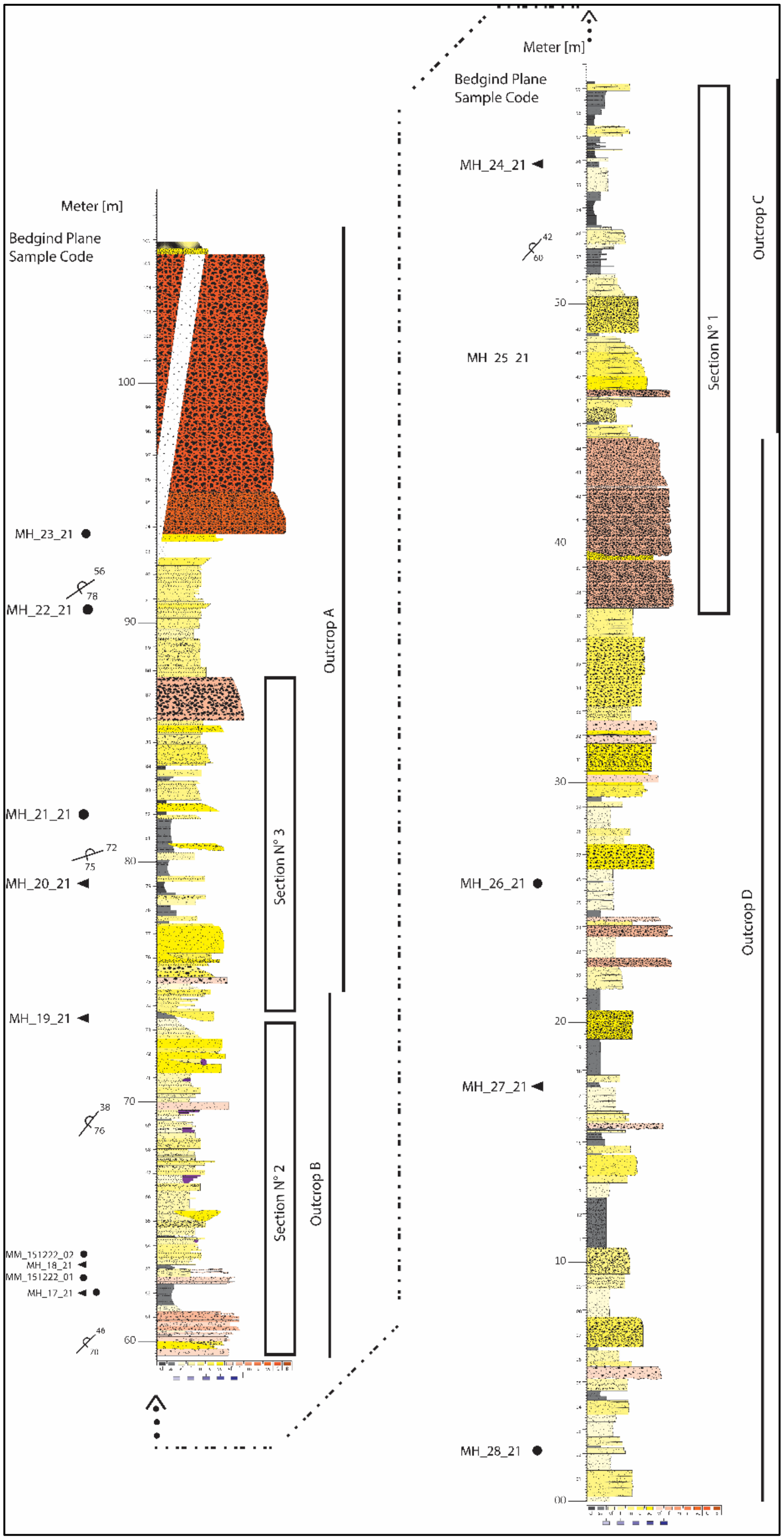

Figure 24.-[Propose stratigraphic column for Lower Chota Member. The stratigraphic record was performed from base to top for the Outcrop D, Outcrop C, Outcrop B, and Outcrop A (Fig. 25). Black dots represent samples used in petrographic studies. Black triangles represent samples used in X-Ray diffraction studies. Stratigraphic Log is reduced 15% of the 1:50 original recorded scale.]

Section N° 01 (Fig. 27) starts on the outcrop D at 1610 m. Asl. and continue until the outcrop D. It describes 23 meters thickness of the Lower Chota Member stratigraphic log. This section, starts at 36 meters and finish at 59 meters and describe the lower-middle section of the Lower Chota Member stratigraphic log. From bottom to top, this section is represented entirely by clastic facies. It starts at the basal part with 1 matter of tabular fine to medium laminated sandstone. Above it there is 5 matters of channelized bad sorted (fine to medium) pebble conglomerates with basal erosive contact. Its present laminated siltstone rip-up clast and volcanic clast in its matrix. Clast present low sphericity and sub-angular roundness. The following 2 meters are represented by channelized bad sorted (very fine to fine) pebble conglomerates with basal erosive contact. Its present volcanic clast with low sphericity and sub-angular roundness. Overlying there is 50 cm of tabular laminated sandstone followed by a 10 cm tabular laminated mudstone. Above this section there is 1.5 matters of (at the base) for a tabular bed of very fine sandstones, its present low sphericity and sub-angular roundness volcanoclastic clast. Follow by a tabular bed of laminated medium sandstones. Finally, at the top there is a tabular clast supported fine pebble conglomerate, its present low sphericity and sub-angular roundness volcanoclastic clast. Above this section there is 2 meters of tabular fining upward sequence of laminated sandstones followed by a tabular fine layer of laminated mudstone. Overlaying this section there is 1.50 meters of tabular matrix-supported coarse sandstones with erosive basal contacts. This layer present volcanic clast with low sphericity and sub-angular roundness, also presents organic debris. Overlaying it there is 9 meters parasequences of mudstones being overlying by channelized laminated sandstones (at the bot) and tabular laminated sandstones (at the top) interpreted as Abandoned Mudstones (AMS) facies interbedded with sandy Delta Front facies.

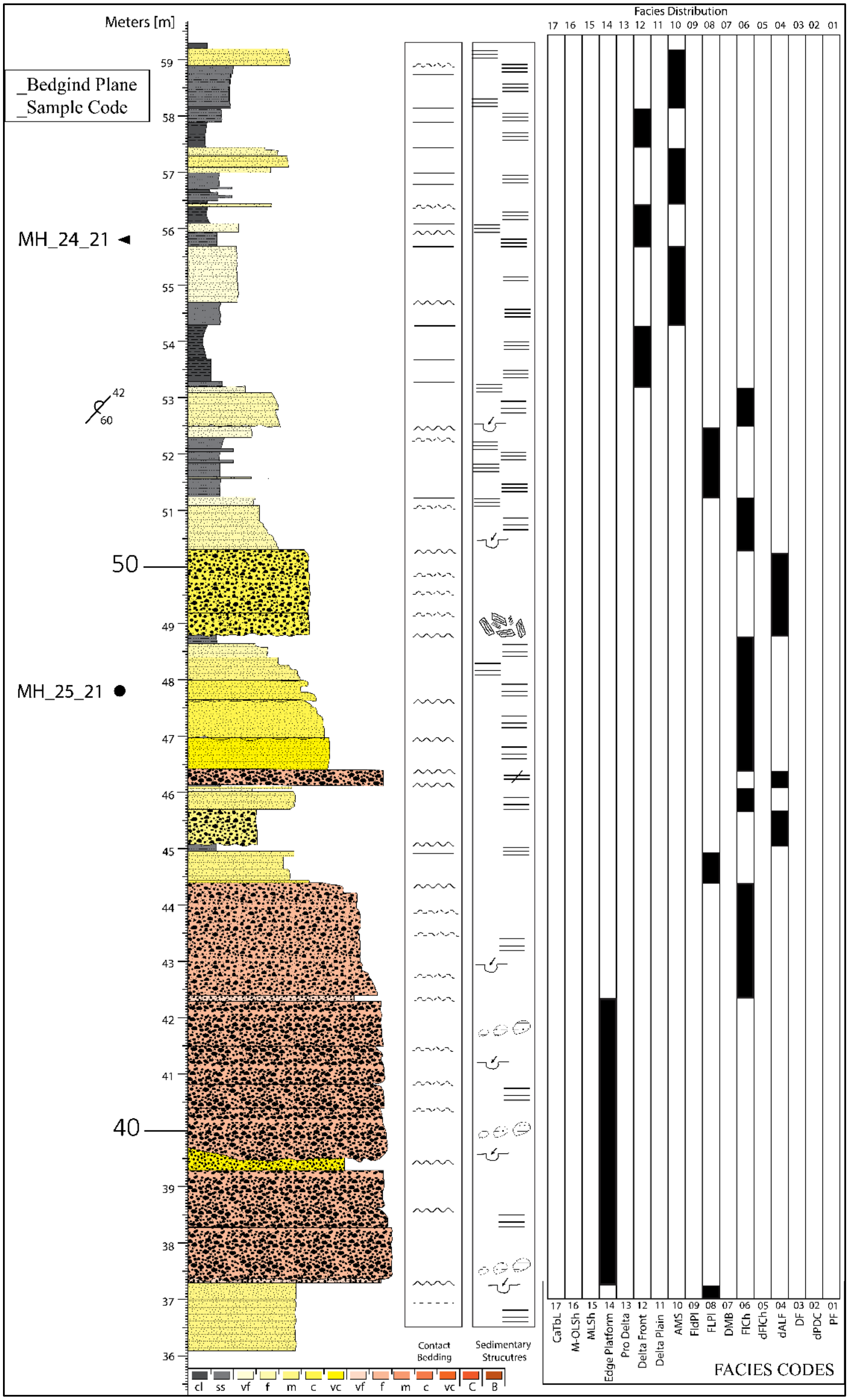

Figure 25.-[Section N° 01 Graphic log at the lower-middle part of the Lower Chota Member. Stratigraphic Log is reduced 50% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Facies Codes (Annex 02, Table 06).]

Section N° 02 (Fig. 28) located on the outcrop B at 1610 m. Asl., It describes 14 meters of thickness. The section starts at 60 meters and finish at 74 meters and describe the middle section of the Lower Chota Member stratigraphic log. From bot to top, it starts at the basal part with tabular massive very fine to fine pebble conglomerates with basal erosive contact, its present low sphericity and sub-angular roundness pumice clast. Overlaying this section there is a 1.5 meter of (at the bottom) tabular laminated sandstone layer followed by (at the top) tabular siltstones. Overlaying this section there is 70 cm of (at the bottom) tabular cross stratified very fine pebble conglomerates with basal erosive contacts overlayed by sandstones layers, followed by tabular laminates siltstones. Above it there is 6.5 meters of interbedded fine- to medium-grained sandstones (with grove casts at the first sandstones layers), and with the occurrence of some weathered beds (calcareous concretions) with calcium carbonate hat not obliterated their primary sedimentary structures. Above it there is 25 cm of tabular massive very fine pebble conglomerate with basal erosive contact, its present low sphericity and sub-angular roundness volcanic clasts. Overlaying this section there is 2.6 meter of coarsening upward tabular cross bedding sandstones sequences with basal erosive contacts, it presents low sphericity and sub-angular roundness volcanic clast. Finally, at the top there is a fining upward laminated sandstones sequences, overlayed by a laminated mudstone follow by a channelized coarse sandstone. Also, the most recurrent clastic sandy facies were fluvial plain (FlPl) followed by distributary mouth bars (DMB), with fine to medium -grained matrix-supported conglomerates of fluvial channels facies (FlCh). In summary, this section is entirely continental, and shows facies of Distal Brained Stream River (dBSR), with the occurrence of the classical Fluvial channels (FlCh), and with interbedded facies of fluvial plain (FlPl) with distributary mouth bars (DMB) and fluvial channels (FlCh).

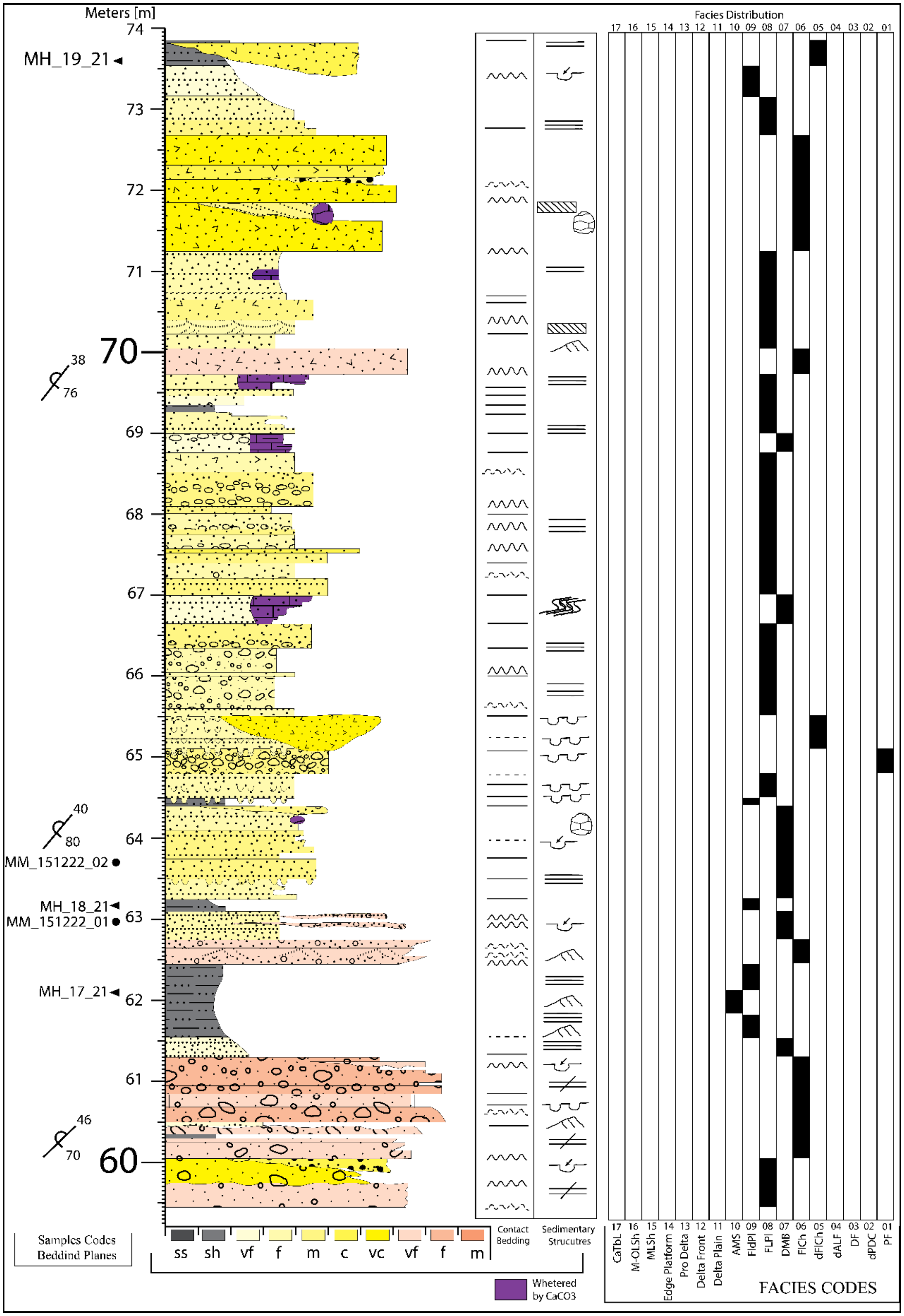

Figure 26.-[Section N° 02 graphic log at the middle-upper part of the Lower Chota Member. Stratigraphic Log is reduced 75% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Facies Codes *(Annex 02, Table 06)*.]

Section N° 03 (Fig. 29) located on the outcrop A at 1637 m. Asl., It describes 14 meters of thickness. The section starts at 74 meters and finish at 87 meters and describe the upper section of the Lower Chota Member stratigraphic log. In general, this section comprises intercalations of matrix-supported conglomerates, horizontally-bedded sandstones and laminated siltstones. Intercalations of fine to medium grained sandstones and mudstones occur in the middle part of this section. From bottom to top, this section is composed of Fluvial Plain facies (FlPl) and Brained Stream River Facies (FlCh) that grades upward, in a retrogradational trend, to fine -to medium- grained sandy (DMB) to laminated muddy facies of Abandoned mudstones (AMS) from Lacustrine Clastic Platform (AMS and DMB), that to the top (above 82 m) are overlying again by Fluvial Plain (FlPl) and Braided Stream River (FlCh) facies. In this section we can appreciate the classical Fluvial Channel (FlCh) models (at the bottom and at the top). In addition, on top of this section is possible to identify conglomerates of Delta Plain (DPl) facies prograding on sandy Fluvial facies (FlCh); and below, the occurrence of a distal pyroclastic density current (dPDC). In summary, this section shows Fluvial Plain (FlPl) and Braided Stream River (BSR) facies retrograding into laminated muddy facies (AMS) from a lacustrine clastic platform (AMS and DMB), that in turn are being overlying by again by prograding BSR and Delta Plain facies. Volcaniclastic activity occurs at the same time with the BSR facies before the AMS and DMB facies.

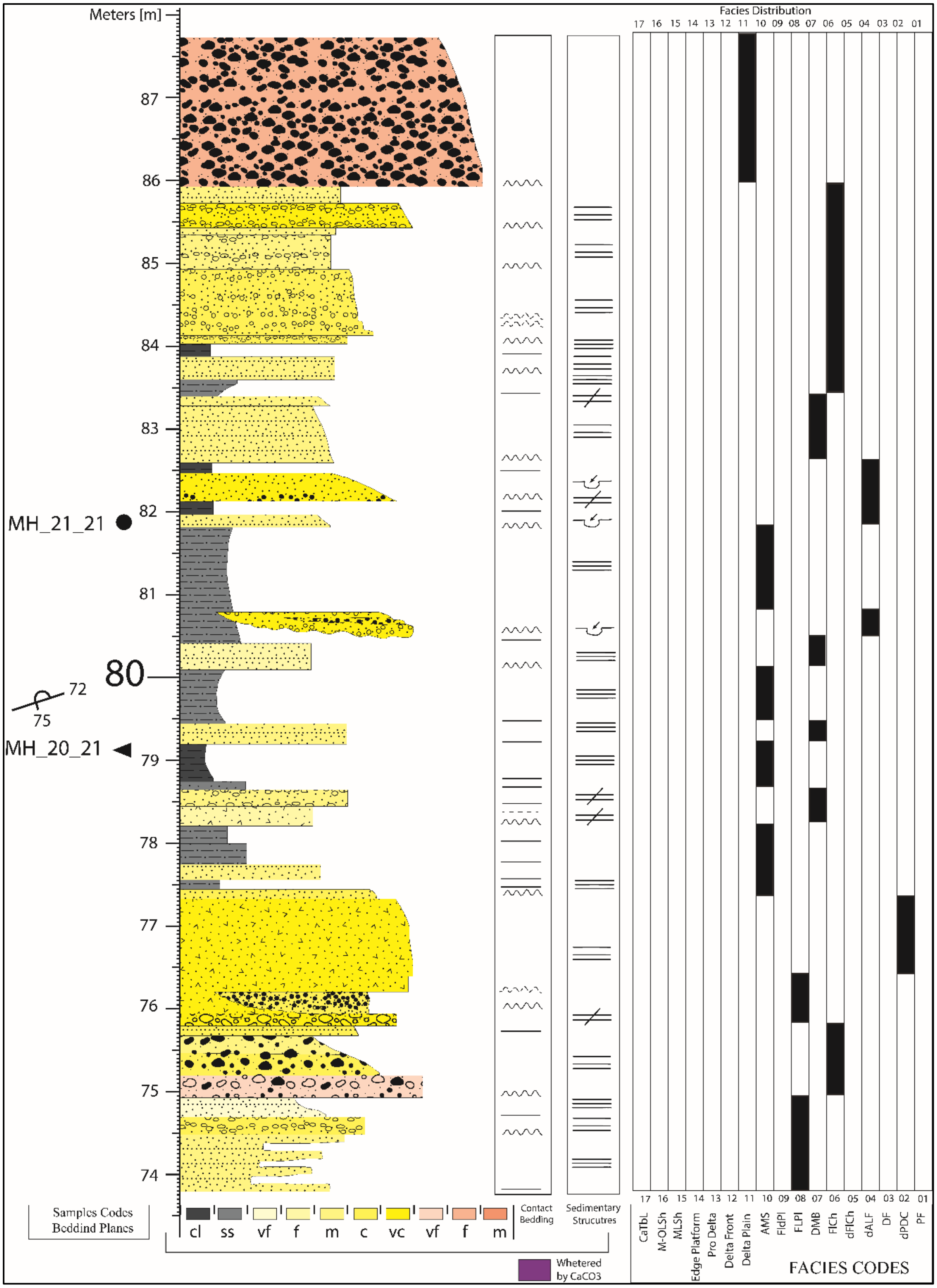

Figure 27.-[Section N° 03 graphic log at the upper part of the Lower Chota Member. Stratigraphic Log is reduced 75% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log Facies Codes *(Annex 02, Table 06)]*

Section N° 04 (Fig. 30) is located South of Chota West town, on the East part of the outcrop E (Fig. 31) at 1581 m. Asl. This section is located at the bottom of the Middle Chota Member Stratigraphic stratigraphically correlated with the Lower Chota Member Stratigraphic log (on the West side). This section describes 22 meters in thickness of clastic silty, sandy and conglomeratic sediments. Its section starts at 13 meters and finish at 35 meters. It describes the upper section of the Lower Chota Member stratigraphic log.

This section (differently than the previous sections) shows: a high occurrence of re-worked sediments (DF., debris flows, with more than 65 % of the total section, medium to coarse grained sandy sediments, and medium to coarse grained matrix-supported conglomerates), located at the base. In the middle and on top of this section; coarse to very coarse grained sandy fluvial sediments (FlCh., proximal fluvial channels, and dFlCh., distal fluvial channels) and sandy to muddy floodplain deposits (FldPl), less than 10 % of the total thickness; sandy facies from a delta environment (DFr, delta front, and DMB, distributary mouth bars), with less than 10 %; and few volcanic activity represented by pyroclastic flow (PF) facies. Then, in this section occurs re-worked sediments (sandy and conglomeratic DF) resulting, from instabilities within the fluvial and delta-plain environments, Delta plain and Fluvial facies; limited by contemporaneous pyroclasts.

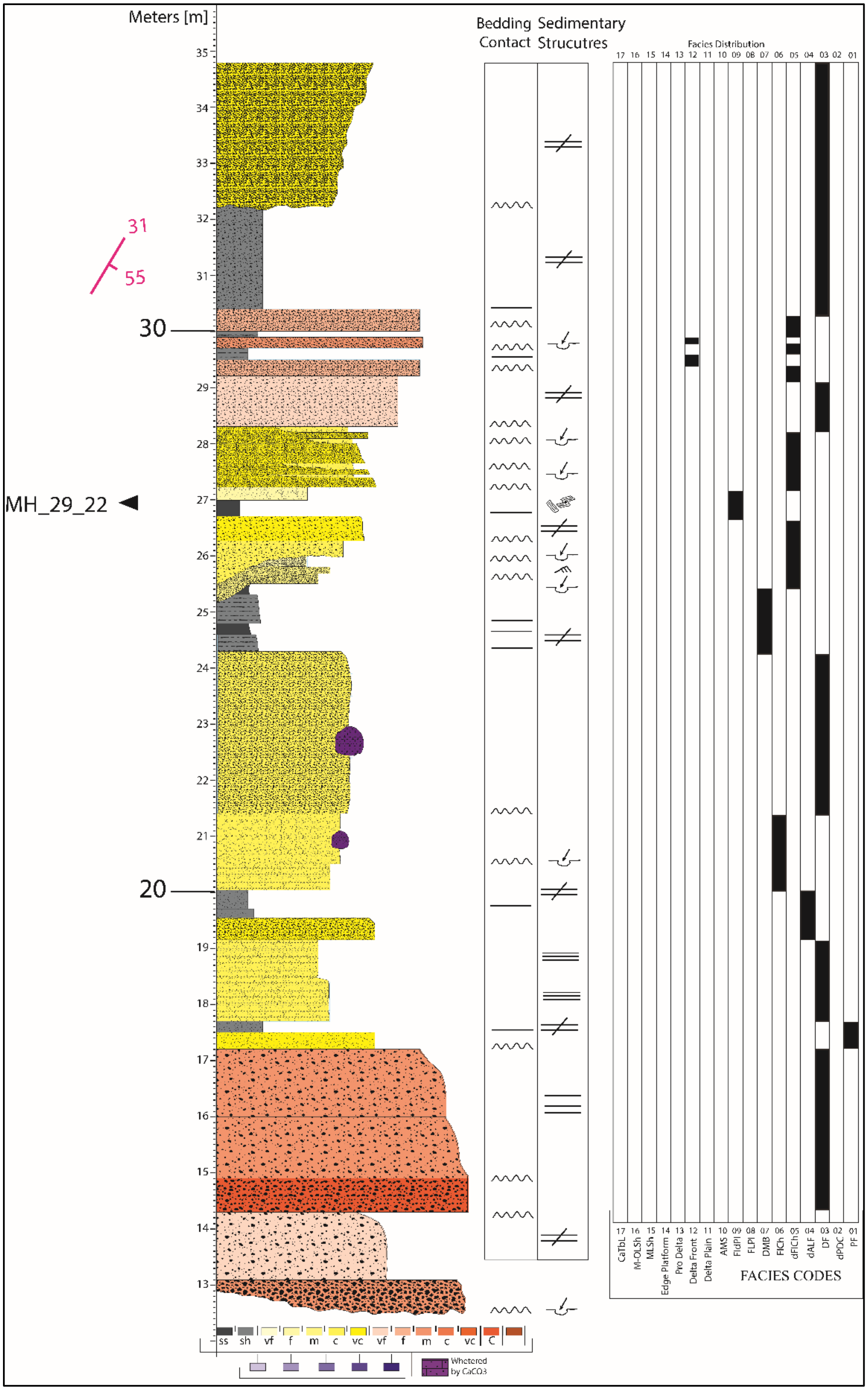

Figure 28.-[Section N° 04 graphic log at the upper part of the Lower Chota Member. Stratigraphic Log is reduced 50% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Red structural data represents faults. Facies Codes *(Annex 02, Table 06)*.]

4.1.2. Middle Chota Member

The Middle Chota Member section was constructed through outcrop E, outcrop F, outcrop G, outcrop H, outcrop I, outcrop J, outcrop K, outcrop L, and outcrop M (Fig. 25 and Fig. 31). It is located Southeast of the Chota West Town. The total recorder section presented for the stratigraphy of Middle Chota Member has a thickness of 225 meters (Fig. 26). At the bottom of the Middle Chota Member Stratigraphic Log is located a Lower Chota Member section which correlates stratigraphically with the stratigraphic log (on the West side). This member describes conglomeratic sediments (at the bottom), limestones (at the middle), and muddy with sandy sediments (at the top). The presence of roots, gastropods and bivalves in the fossils record are important markers characteristics of this member. For this study I focus the analysis description on two sections of the Middle Chota Member located at the bottom part of the stratigraphic log (Fig. 31). From bottom to top: Section N° 05 (Fig. 32) and Section N° 06 (Figure 33).

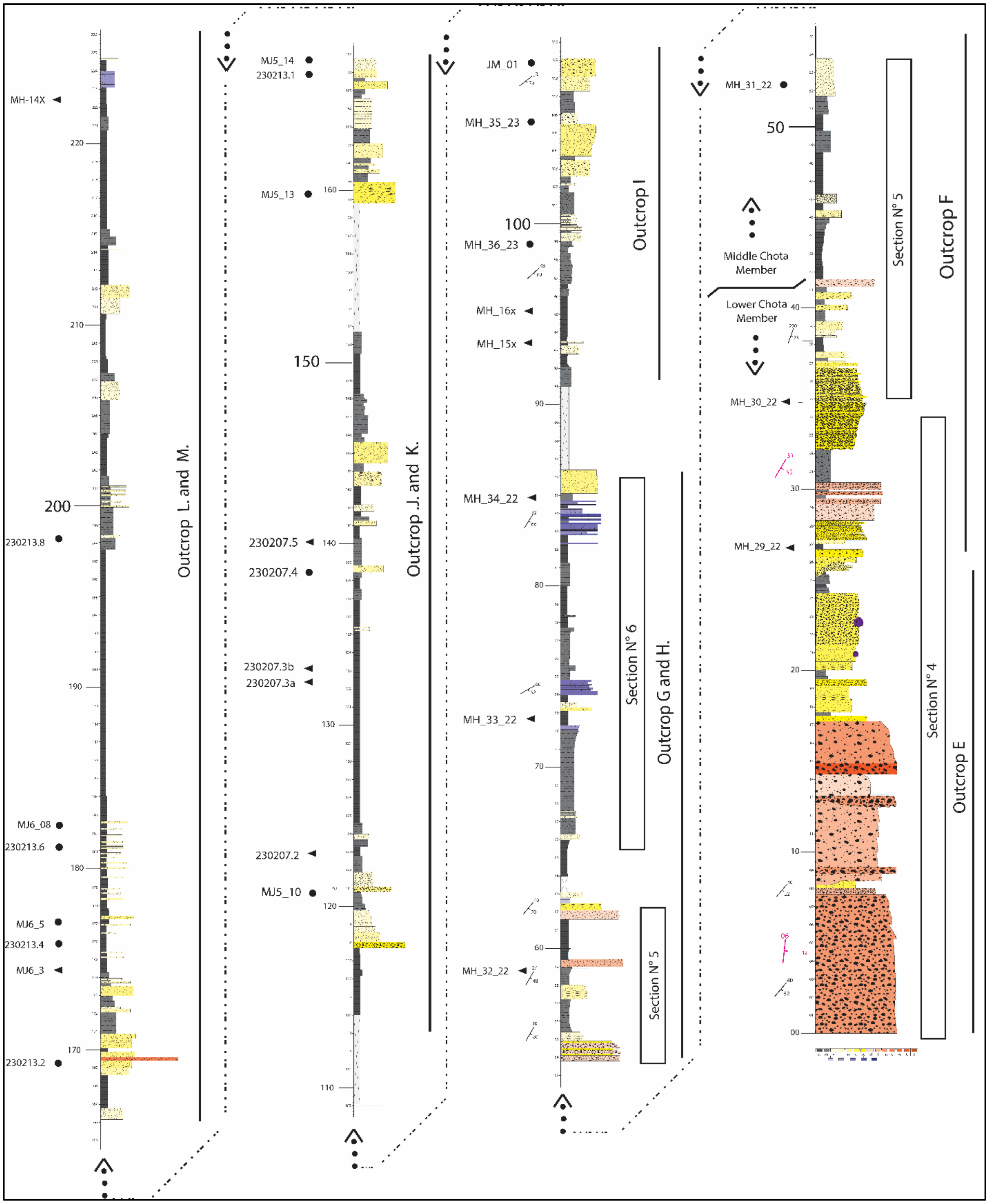

Figure 29.-[Propose stratigraphic column for Middle Chota Member. The stratigraphic record was performed from base to top for the Outcrop E, Outcrop F, Outcrop G, Outcrop H, Outcrop I, Outcrop J, Outcrop K, Outcrop L, and Outcrop M (Fig. 25). Black dots represent samples used in petrographic studies. Black triangles represent samples used in X-Ray diffraction studies. Black structural data represents strike and dip measurements. Red structural data represents faults. Stratigraphic Log is reduced 15% of the 1:50 original recorded scale.]

Section N° 05 (Fig. 32) located on the outcrop F and outcrop G (Fig. 31) at 1637 m. Asl., describes 27 meters of thickness. It is located Southeast of Chota town. The section starts at 35 meters and finish at 62 meters, it describes the lower section of the Middle Chota Member stratigraphic log. From bottom to top, the first 3 meters is represented by sandy to conglomeratic sediments. Above these sediments (approximately at 39 meters) is located the transition zone transition (Fig. 32) from the Lower Chota Member to the Middle Chota Member. Above this zone (now bedding to the East-Southeast) there is and occurrence of a net progradational tendency in the low order sequences. The sequences are between 4 to 9 meters in thickness, and shows a net progradation of facies, with basal erosive surfaces, from claystones, shales, siltstones and very fine to very coarse sandstones, from Pro-delta (ProD) and Delta front (DFr) to Delta plain (DPl), Fluvial plain (FlPl), Flood plain (FldPl), Distributary mouth bars (DMB) and Fluvial channels (FlCh), and again being overlying by another prograding sequence. This organization shows the continental progradational character at the basal part of the Middle Chota Member, composed by several deltaic and distal fluvial sequences, synonymous of an active compressive regional setting.

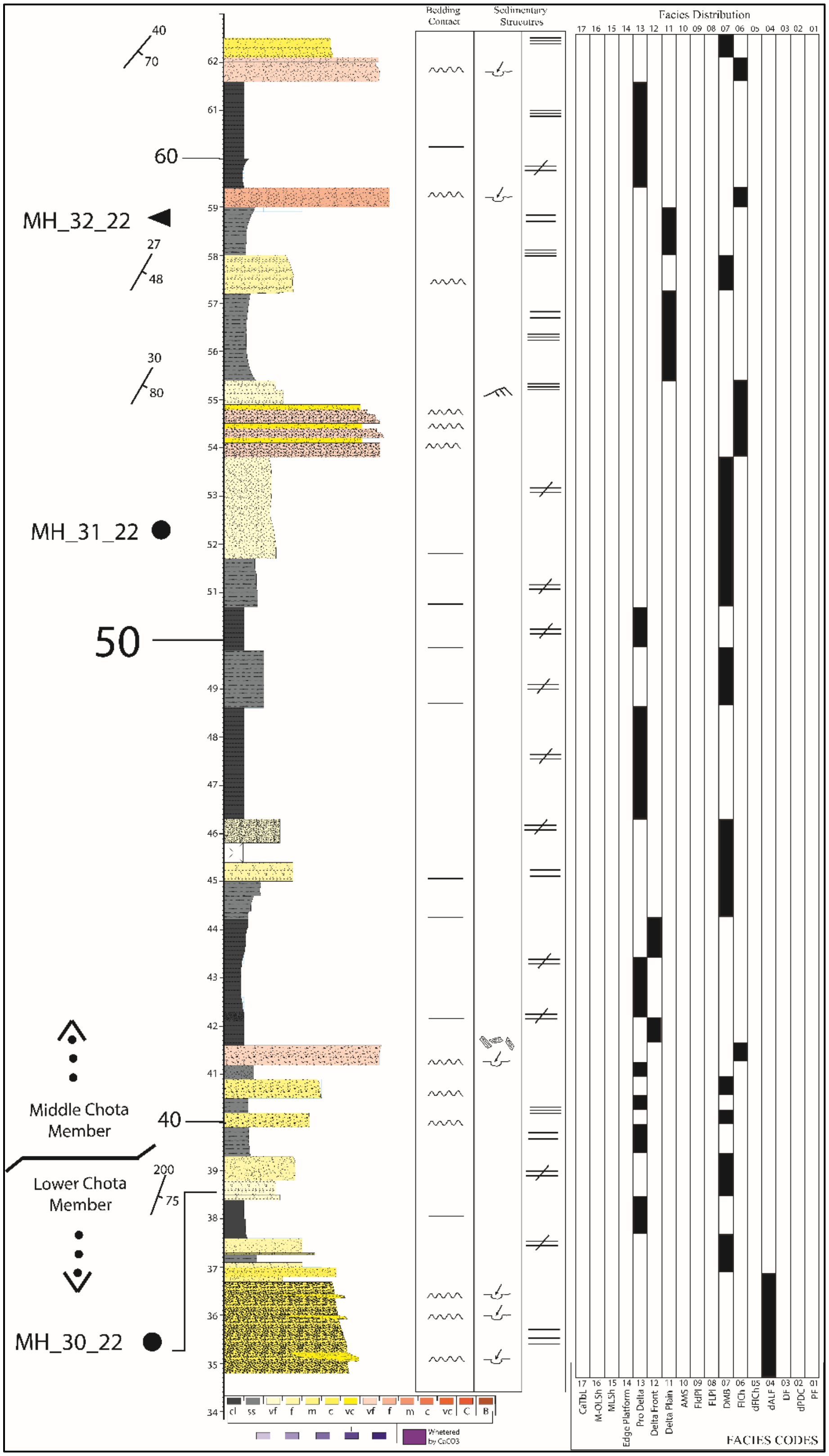

Figure 30.-[Section N° 05 graphic log at the lower part of the Middle Chota Member. Stratigraphic Log is reduced 40% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Red structural data represents faults. Facies Codes *(Annex 02, Table 06)*.]

Section N° 06 (Fig. 33) located on the outcrop G and outcrop H (Fig. 31) at 1584 m. Asl., describes 22 meters of thickness. It is located Southeast of Chota town. The section starts at 64 meters and finish at 86 meters, it describes the lower-middle section of the Middle Chota Member stratigraphic log. From this section onwards occur not only the classical clastic facies (claystones, siltstones, and very-fine- to fine-grained sandstones), also occur calcareous fossiliferous facies (mudstones MS, wackestones WS and packstones PS, plenty of white deformed gastropods). The fossil content, mainly composed by 2 to 10-mm in length gastropods (Annex 03. Fig. 47), very few fragments of fish bones and fish teeth.

The lower part of this section registers the occurrence of near 5-m in thickness Debris flow (DF), composed by volcano-clastic components, overlying mainly Pro-delta (ProD) and eventually Distributary mouth bar facies (DMB). From the middle to the upper part of this section were identified mixed facies from mainly the Middle shelf, organized apparently in an aggrading style: composed by white to cream fossiliferous limestones (CaTb, re-worked sediments within the shelf, entrained in a turbiditic process), Middle to Outer shelf (M-OSh) (brown to gray claystones, shales and siltstones) and Middle to Internal shelf (MISh) siltstones. Also, in addition to gastropods, in this section is possible to find debris of fragments of bushes and bivalves.

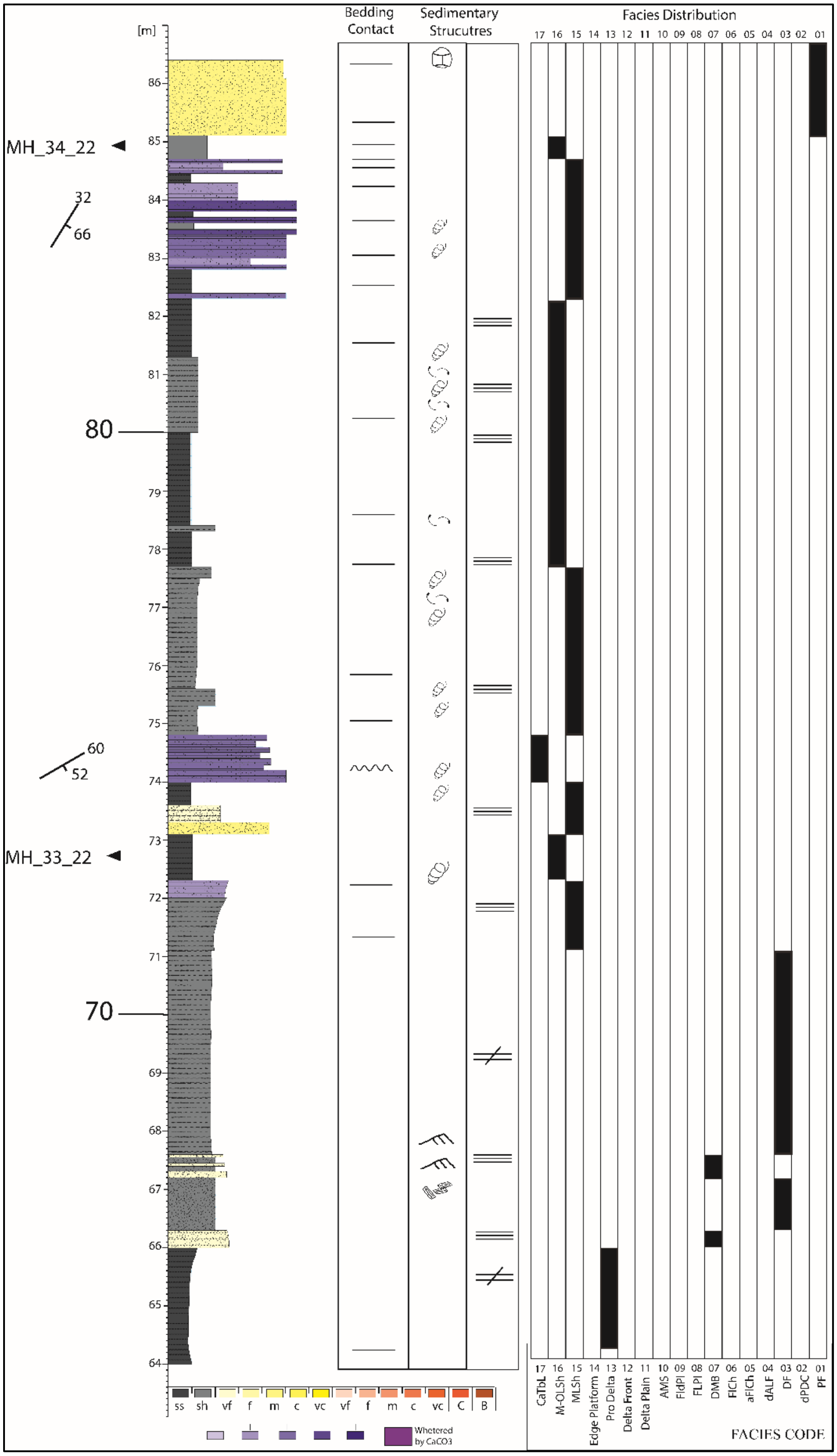

Figure 31.-[Section N° 06 graphic log at the lower part of the Middle Chota Member. Stratigraphic Log is reduced 50% of the 1:50 original recorded scale. Samples location and structural data showing at the left side of the log. Black structural data represents Strike and Dip. Facies Codes *(Annex 02, Table 06).*]

4.2. Sample Collection Results

Forty-three (42) rock samples were collected in this study: 19 mudstones, 22 sandstones, and 1 igneous. Twenty-three (23) samples were used for petrographic analysis and eighteen (18) samples were used for X-Ray Diffraction analysis (Table 01).

Table 1.[Samples collected in the study. "Sample Name" represents the name assigned on field at the moment of collect the sample and the "Variable Name" is the name assigned for the study. In the section of Petrographic and X-Ray zero (0) means "no sample collected" and one (1) means "sample collected". X and Y represent coordinates values (Datum: WGS 84. Projection: UTM 17N.).]

Section	*Sample Name*	*Variable Name*	*Petrographic*	*X-Ray*	*X*	*Y*	*m. Asl.*
Lower	*SM_09*	*CH_44*	*1*	*0*	*826243.00*	*51932.45*	*1581.0*
Middle	*MH_14x*	*CH_42*	*0*	*1*	*826,600.53*	*51,571.06*	*1605.0*
Middle	*230213.8 / MJ06_09*	*CH_41*	*1*	*0*	*826588.58*	*51581.13*	*1595.3*
Middle	*MJ6_08*	*CH_43*	*1*	*0*	*826638.51*	*51617.46*	*1600.0*
Middle	*230213.6 / MJ06_07*	*CH_40*	*1*	*0*	*826648.97*	*51611.51*	*1583.7*
Middle	*MJ6_05*	*CH_39*	*1*	*0*	*826646.42*	*51621.34*	*1620.0*
Middle	*230213.4*	*CH_38*	*1*	*0*	*826,637.44*	*51,620.27*	*1596.0*
Middle	*Mh17x / MJ6_03*	*CH_37*	*0*	*1*	*826646.42*	*51621.34*	*1620.0*
Middle	*230213.2*	*CH_36*	*1*	*0*	*826,634.27*	*51,622.65*	*1595.0*
Middle	*MJ5_14*	*CH_35*	*1*	*0*	*826635.74*	*51630.58*	*1586.9*
Middle	*230213.1*	*CH_34*	*1*	*0*	*826,635.46*	*51,634.95*	*1590.0*
Middle	*MJ5_13*	*CH_33*	*1*	*0*	*826638.83*	*51635.70*	*1586.4*
Middle	*230207.5*	*CH_32*	*0*	*1*	*826,667.73*	*51,672.42*	*1591.0*
Middle	*230207.4*	*CH_31*	*1*	*0*	*826,667.06*	*51,673.08*	*1590.0*
Middle	*230207.3b*	*CH_30*	*0*	*1*	*826,662.70*	*51,675.20*	*1588.0*
Middle	*230207.3a*	*CH_29*	*0*	*1*	*826,663.89*	*51,674.67*	*1588.0*
Middle	*230207.2*	*CH_28*	*0*	*1*	*826,660.19*	*51,677.97*	*1585.0*
Middle	*MJ5_10*	*CH_27*	*1*	*0*	*826691.06*	*51732.12*	*1619.0*
Middle	*JM_01*	*CH_26*	*1*	*0*	*826496.03*	*51611.11*	*1654.0*
Middle	*MH_35_23*	*CH_25*	*1*	*0*	*826507.00*	*51606.65*	*1640.0*
Middle	*MJ-06 / MH_36_23*	*CH_24*	*1*	*0*	*826511.71*	*51606.03*	*1630.0*
Middle	*MH_16x*	*CH_23*	*0*	*1*	*826519.33*	*51603.49*	*1625.0*
Middle	*MH_15x*	*CH_22*	*0*	*1*	*826522.82*	*51603.01*	*1624.0*
Middle	*MH_34_22*	*CH_21*	*0*	*1*	*826579.10*	*51752.15*	*1620.0*
Middle	*MH_33_22*	*CH_20*	*0*	*1*	*826618.20*	*51844.08*	*1604.0*
Middle	*MH_32_22*	*CH_19*	*0*	*1*	*826640.37*	*51897.55*	*1576.0*
Middle	*MH_31_22*	*CH_18*	*1*	*0*	*826637.98*	*51901.52*	*1577.5*
Lower	*MH_30_22*	*CH_17*	*0*	*1*	*826646.51*	*51957.26*	*1573.1*
Lower	*MH_29_22*	*CH_16*	*0*	*1*	*826626.82*	*51968.94*	*1578.0*
Lower	*MH_23_21*	*CH_14*	*1*	*0*	*826199.58*	*52008.52*	*1626.0*
Lower	*MH_22_21*	*CH_13*	*1*	*0*	*826201.49*	*52004.24*	*1624.0*

Section	Sample Name	Variable Name	Petrographic	X-Ray	X	Y	m. Asl.
Lower	MH_21_21	CH_12	1	0	826251.27	51986.63	1590.0
Lower	MH_20_21	CH_11	0	1	826256.97	51984.57	1595.0
Lower	MH_19_21	CH_10	0	1	826272.07	51969.35	1567.0
Lower	MM_151222_02	CH_09	1	0	826257.70	51954.79	1574.5
Lower	MH_18_21	CH_08	0	1	826263.50	51949.05	1575.7
Lower	MM_151222_01	CH_07	1	0	826255.02	51946.96	1576.0
Lower	MH_17_21	CH_06	1	1	826263.50	51949.05	1575.7
Lower	MH_24_21	CH_05	0	1	826264.91	51947.62	1604.0
Lower	MH_25_21	CH_04	0	0	826268.14	51945.43	1585.0
Lower	MH_26_21	CH_03	1	0	826311.32	51938.87	1600.0
Lower	MH_27_21	CH_02	0	1	826312.19	51931.99	1605.0
Lower	MH_28_21	CH_01	1	0	826312.40	51925.96	1610.0

4.3. Petrographic Results

Twenty-three (23) rock samples were analyzed under the binocular stereoscopic microscope to identify the occurrence of minerals. Giving as a result of twenty-three (23) sedimentary petrographic descriptions (Table 02) and one (1) igneous petrographic description (Annex 01. Fig. 46).

Table 2.-[Sedimentary petrographic descripted samples. "Variable Name" is the name assigned to the "Sample Name" for the study. Key: Cement. Feldspar. Matrix (Mx). Metamorphic Quartz (Qmet). Volcanic Quartz (Qvolc). Lithics Volcanic (Lvolc). Sedimentary Lithics (Lsed). Metamorphic Lithics (Lmet). Heavy Minerals (HM).]

Member	Variable Name	Mx	Cement	Qmet	Qvol	Feldspars	Lvolc	Lsed	Lmet	HM
Middle	CH_41	0.00	0.25	1.00	20.00	41.00	1.00	0.00	0.00	36.75
Middle	CH_43	0.00	2.00	1.00	15.00	29.25	0.75	48.40	0.00	3.60
Middle	CH_40	1.50	0.00	5.00	66.25	18.75	2.25	0.00	0.00	6.25
Middle	CH_39	0.00	0.25	2.00	58.00	22.15	2.10	0.00	0.00	15.50
Middle	CH_38	1.00	0.25	0.25	57.25	22.00	1.65	0.00	0.00	17.60
Middle	CH_36	3.00	0.25	0.00	87.00	4.00	0.65	2.50	0.25	2.35
Middle	CH_35	0.25	0.25	2.50	73.00	9.00	1.00	0.00	0.00	14.00
Middle	CH_34	0.00	0.25	0.50	34.50	53.75	3.85	0.00	0.00	7.15
Middle	CH_33	7.00	0.25	0.00	15.00	41.00	7.45	0.00	0.00	29.30
Middle	CH_31	0.00	0.00	0.00	29.00	46.75	11.50	10.00	0.00	2.75
Middle	CH_27	4.00	0.00	4.00	76.00	11.00	1.25	2.00	1.00	0.75
Middle	CH_25	6.00	0.00	0.25	30.75	40.70	10.10	7.00	0.00	5.20
Middle	CH_24	5.00	0.25	0.00	25.00	53.00	14.70	0.00	0.00	2.05

Member	*Variable Name*	*Mx*	*Cement*	*Qmet*	*Qvol*	*Feldspars*	*Lvolc*	*Lsed*	*Lmet*	*HM*
Middle	*CH_18*	*7.00*	*0.00*	*0.00*	*40.00*	*47.40*	*0.10*	*3.00*	*0.00*	*2.50*
Lower	*CH_14*	*1.00*	*0.25*	*3.00*	*41.25*	*40.00*	*6.50*	*0.25*	*0.00*	*7.75*
Lower	*CH_13*	*0.00*	*1.00*	*0.00*	*50.00*	*8.00*	*37.00*	*1.00*	*0.25*	*2.75*
Lower	*CH_12*	*1.00*	*0.25*	*0.00*	*65.00*	*24.70*	*0.55*	*0.25*	*0.25*	*8.00*
Lower	*CH_09*	*2.00*	*0.00*	*0.00*	*93.75*	*2.00*	*0.50*	*0.00*	*0.00*	*1.75*
Lower	*CH_07*	*0.00*	*0.25*	*0.00*	*43.00*	*45.60*	*2.00*	*1.50*	*0.25*	*7.40*
Lower	*CH_06*	*1.50*	*0.25*	*0.00*	*37.00*	*55.50*	*2.00*	*0.25*	*0.00*	*3.50*
Lower	*CH_03*	*0.25*	*2.55*	*2.00*	*30.00*	*31.00*	*25.10*	*0.50*	*0.00*	*8.60*
Lower	*CH_01*	*1.00*	*0.25*	*2.00*	*25.00*	*31.00*	*33.25*	*0.25*	*0.00*	*7.25*

4.3.1. Bar Diagram Results

A bar diagram expresses graphically well the total occurrence of minerals identified under the binocular stereoscopic microscope. In this study, for well illustrating the occurrence of minerals and lithic fragments, from bottom to top, three different bar diagrams are presented: (1) a bar diagram including all analyzed samples (Fig. 34), (2) a bar diagram including the petrographic results from the Lower Chota Member (Fig. 35), and (3) a bar diagram including the petrographic results from the Middle Chota Member (Fig. 36). In these figures, samples are represented in stratigraphic order from top to bottom in the left right way.

The Matrix (Mx) content in the analyzed clastic samples was composed by silty, semi-consolidated grains, subangular, with a variable composition, more leucocratic (plagioclases) in appearance. The characteristics of grains of metamorphic quartz (Qmet) are pale gray in color, subangular to subrounded, with some fractures cut-crossing the grains. The characteristics of grains of volcanic quartz (Qvolc) are white to pale cream in color, clean, subrounded, with rare fractures, translucide, some of them transparents. The feldspars, composed by potassium feldspars (K-feldspars) and plagioclases, in these samples are mainly composed by plagioclases, white to cream in color, tabulars, with some clear cleavage planes, subangulars, and more probably corresponding to a composition from albite (An0-10) to oligoclase (An10-30), with rare andesine (An30-50). The volcanic lithic fragments (Lvolc) occurring in these sediments are composed by gray fragments of tefras, low vesiculated grains of white pumices, gray to pale gray andesitic to dacitic grains, and white rhyolitic grains, with grains more cream to pale gray grains. The sedimentary lithic fragments (Lsed) occurring in these sediments are composed of laminated, subrounded, gray to cream, medium to very fine grained sandy to silty demi-consolidated clastic grains. The metamorphic lithic fragments (Lmet) occurring in these sediments are composed by subrounded gray to black shales and fine- to very fine-grained laminated quartzites. Finally, the heavy minerals (HM) found in these sediments were composed by deep gray to black grains, some brilliants, subrounded to subangular, some of the subhedral to euhedrals, some fractured, composed mainly by: unstable minerals, as tabular black to deep green olive amphiboles, rare tabular black pyroxenes; and moderately stable to relatively stable minerals composed by black crystals of subrounded to subangular magnetite, ilmenite and titanite, and rare tabular brown zircons, following the classification proposed by Garzanti et al. (2018).

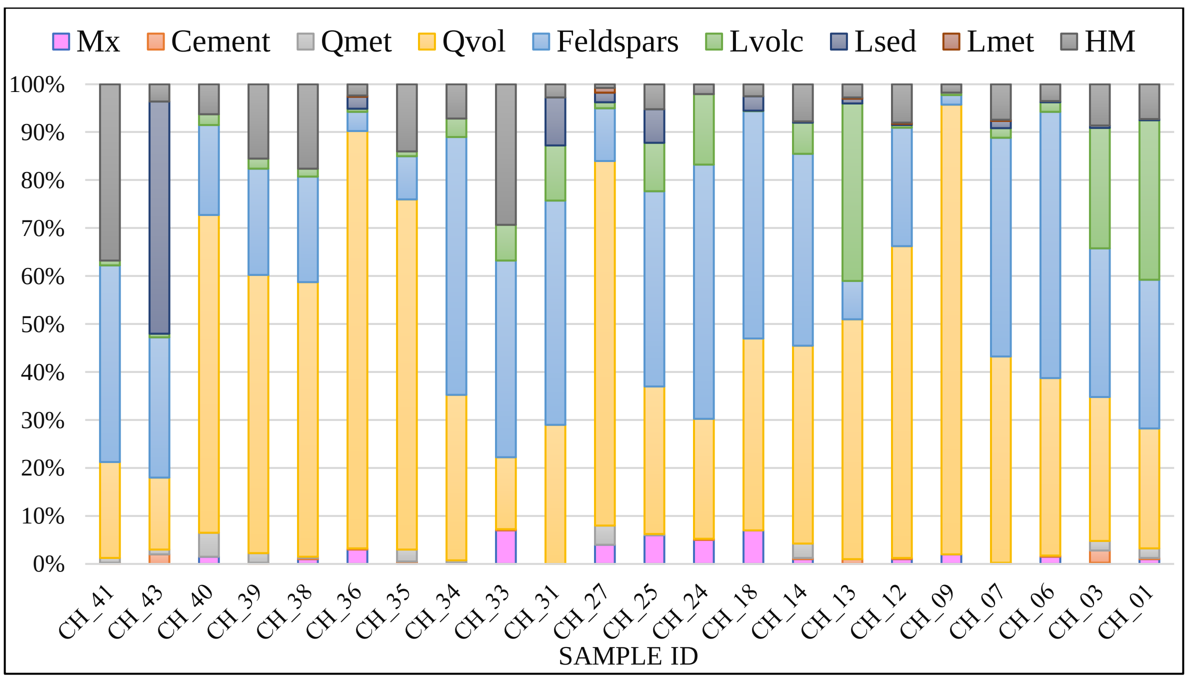

Figure 32.-[West Chota Formation Rock Composition. Total samples, n = 22. Bar diagram expressing the total occurrence of minerals and lithic fragments identified in 22 samples from the Lower Chota Member and the Middle Chota Member analyzed under the stereoscopic microscope. Key: Cement. Feldspar. Matrix (Mx). Metamorphic Quartz (Qmet). Volcanic Quartz (Qvolc). Lithics Volcanic (Lvolc). Sedimentary Lithics (Lsed). Metamorphic Lithics (Lmet). Heavy Minerals (HM). Base percentage mineral abundance (Table 04).]

Samples from the Lower Chota Member show, from bottom to top (Fig. 26) or from right to left (Fig. 35), a gradual increase in the abundance of Qvolc, from 28% to 66% and 96%, and an ulterior stabilization between 46 to 51%. At the same time, from bottom to top, there is an increase in the abundance of leucocratic plagioclases, from 31% to 45% and 55%, and after that until 40% to 45%. The occurrence of volcanic lithic fragments (Lvolc) is variable, from 33% decreasing to near to 1% in the middle part, repeating this decreasing trend to the top, from 37% to near to zero. Finally, the abundance of heavy minerals (HM) is near uniform, constant, between rarely 2% as minimum to more frequently until 9% (Fig.34). Furthermore, the occurrence of these minerals and lithic fragments in the Lower Chota Member evidences the contemporaneous acid to intermediate volcaniclastic activity, from a volcanic contemporaneous source producing medium to very fine-grained volcanic grains, releasing to the atmosphere a rhyolitic to dacitic products ulteriorly reworked in medium to very fine, grained sandstones.

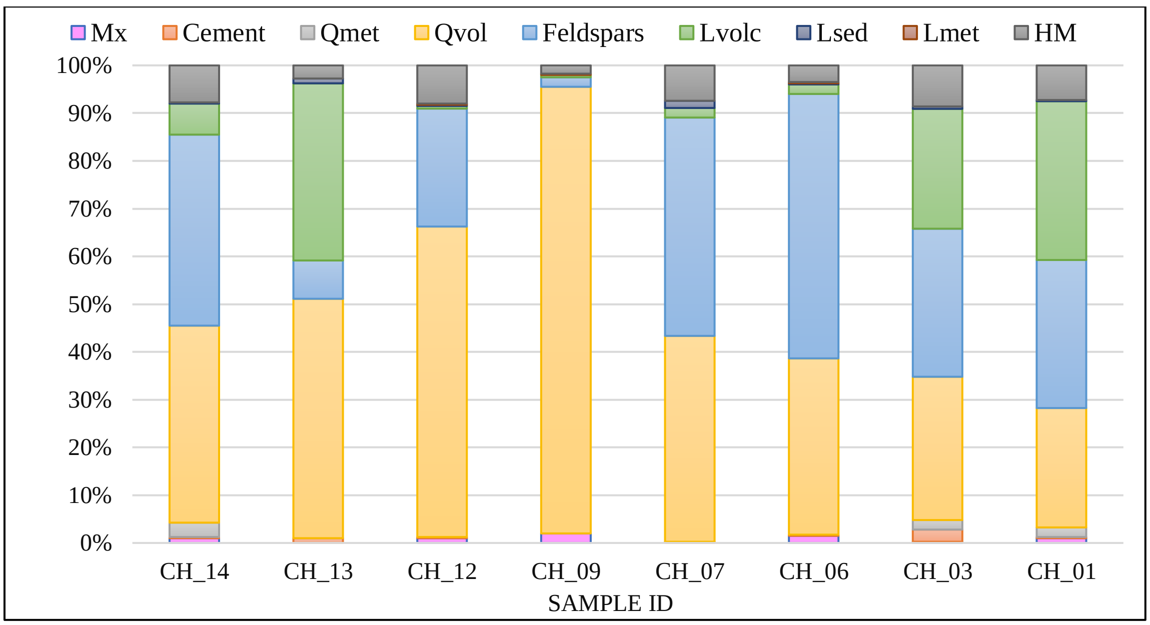

Figure 33.-[Lower Chota Member Rock Composition. Total samples, n = 08. Bar diagram expressing the total occurrence of minerals and lithic fragments identified in 08 samples from the Lower Chota Member under the stereoscopic microscope. Key: Cement. Feldspar. Matrix (Mx). Metamorphic Quartz (Qmet). Volcanic Quartz (Qvolc). Lithics Volcanic (Lvolc). Sedimentary Lithics (Lsed). Metamorphic Lithics (Lmet). Heavy Minerals (HM).]

Samples from the Middle Chota Member show (Fig. 36), from bottom to top, a roughly gradual increase in the abundance of Qvolc, from 25% at the bottom to 65% near to the top. At the same time, from bottom to top, there is roughly a decrease in the abundance of leucocratic Plagioclases, from 53% to near to 20%, and a sudden increase near to the top until 41% and 30%. The occurrence of volcanic lithic fragments (Lvolc) shows a clear, net decrease in abundance, from 15% decreasing to near to 1% at the top. The sedimentary lithic fragments (Lsed) show a variable behavior, with a range of abundances with no trend, from near to zero to exceptionally to 49%, normally about 4%. Finally, the abundance of heavy minerals (HM) shows an increase, from 2% to 5% to 37%. Furthermore, the occurrence of these minerals and lithic fragments in the Middle Chota Mb evidences the contemporaneous acid to intermediate volcaniclastic activity, from a volcanic contemporaneous source, producing fine to very fine grained volcanic grains, releasing to the atmosphere rhyolitic products ulteriorly reworked in the basin in fine to very fine grained sandstones and silty sandstones.

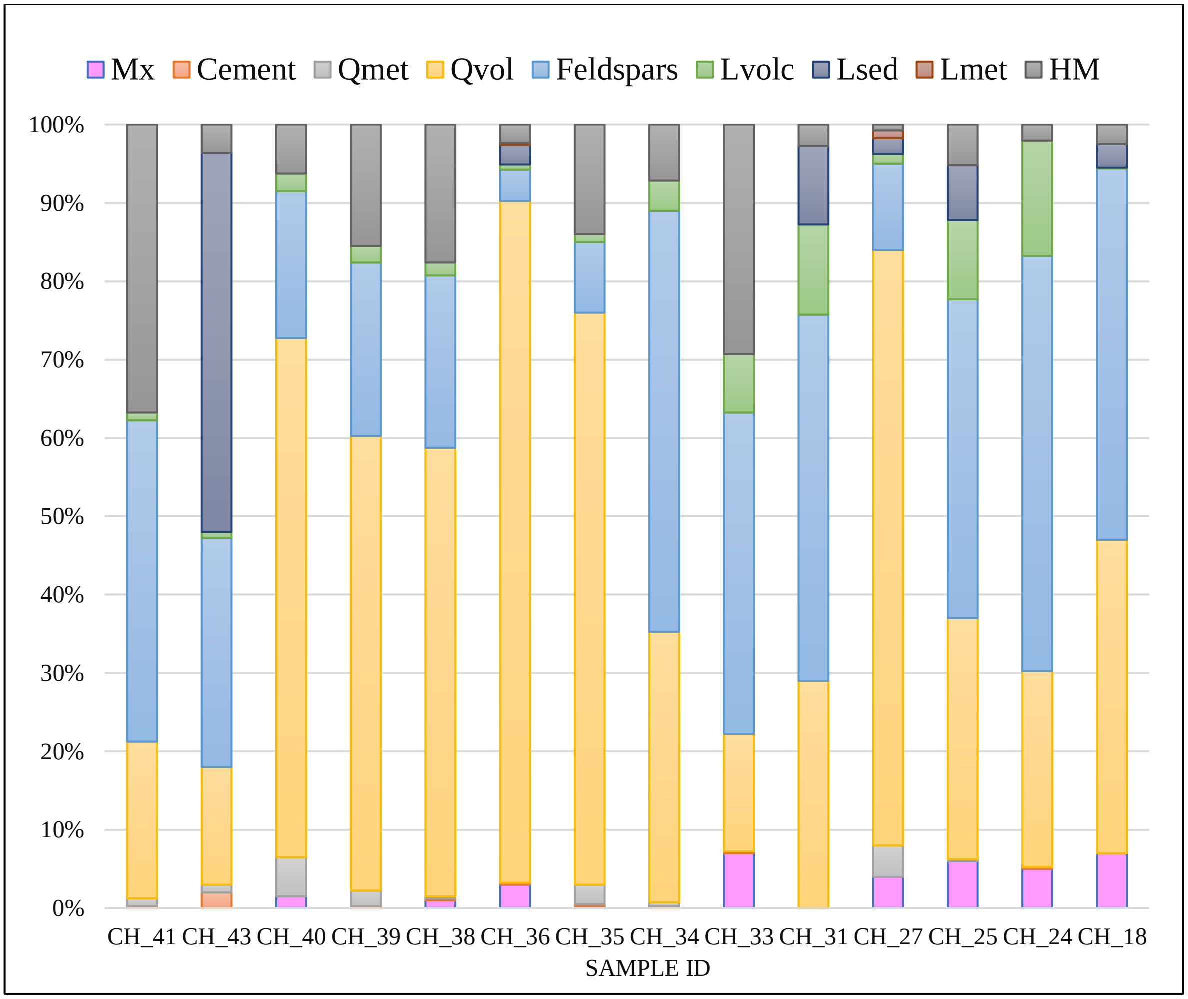

Figure 34.-[Middle Chota Member Rock Composition. Total samples, n = 14. Bar diagram expressing the total occurrence of minerals and lithic fragments identified in 14 samples from the Middle Chota Member under the stereoscopic microscope. Key: Cement. Feldspar. Matrix (Mx). Metamorphic Quartz (Qmet). Volcanic Quartz (Qvolc). Lithics Volcanic (Lvolc). Sedimentary Lithics (Lsed). Metamorphic Lithics (Lmet). Heavy Minerals (HM).]

4.3.2. Triangular QFL Folk Diagram Results

In terms of composition, the Lower Chota Member shows a variable composition, following the classification of sandstones after Folk (1956): mainly composed of arkoses and lithic-arkoses (Fig. 37., Fig.38., & Fig. 40), with low to moderate content of Quartz. Instead, the Middle Chota Member shows a composition, richer in Quartz, composed of sub-arkoses, arkoses and lithic arkoses (Fig. 37., Fig.39., & Fig. 40),

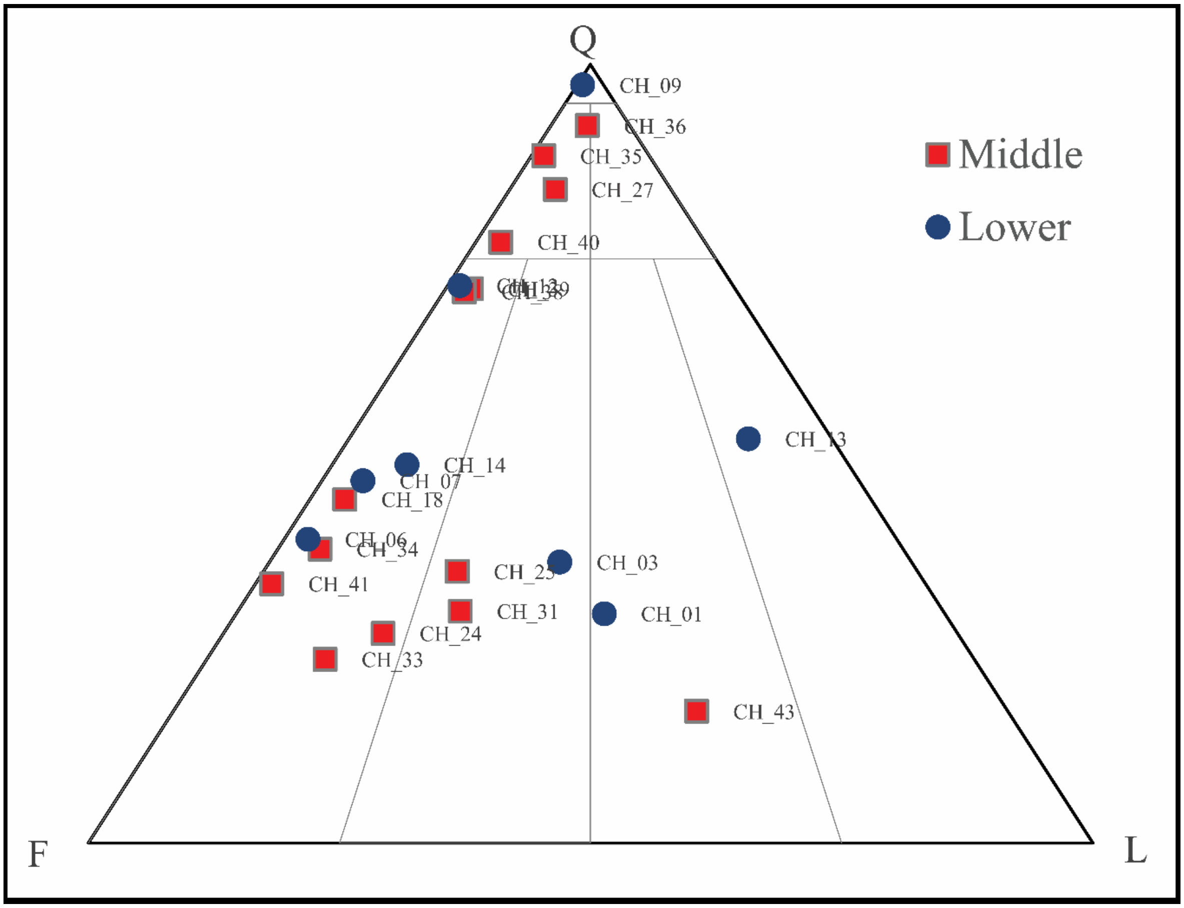

Figure 35.-[QFL Folk diagram of the Lower Chota Member and Middle Chota Member sandstone samples. Classification of sandstones are in the triangular diagram QFL from Folk (1956) (Fig. 23.B). Blue dots represent the Lower Chota Member samples. Red squares represent the Middle Chota Member samples. Key: Quartz content (Q). Feldspar content (F). Lithic content (L). Total samples, n = 22.]

Lower Chota Member QFL Folk diagram (Fig. 38) shows eight (8) samples. The position of each sample represents a specific classification name. From bot to top, Lower Chota Member generate the following results: CH_01 (Feldspathic Litharenite), CH_03 (Lithic Arkose), CH_06 (Arkose), CH_07 (Arkose), CH_09 (Quartzarenite), CH_12 (Arkose), CH_13 (Litharenite), CH_14 (Arkose).

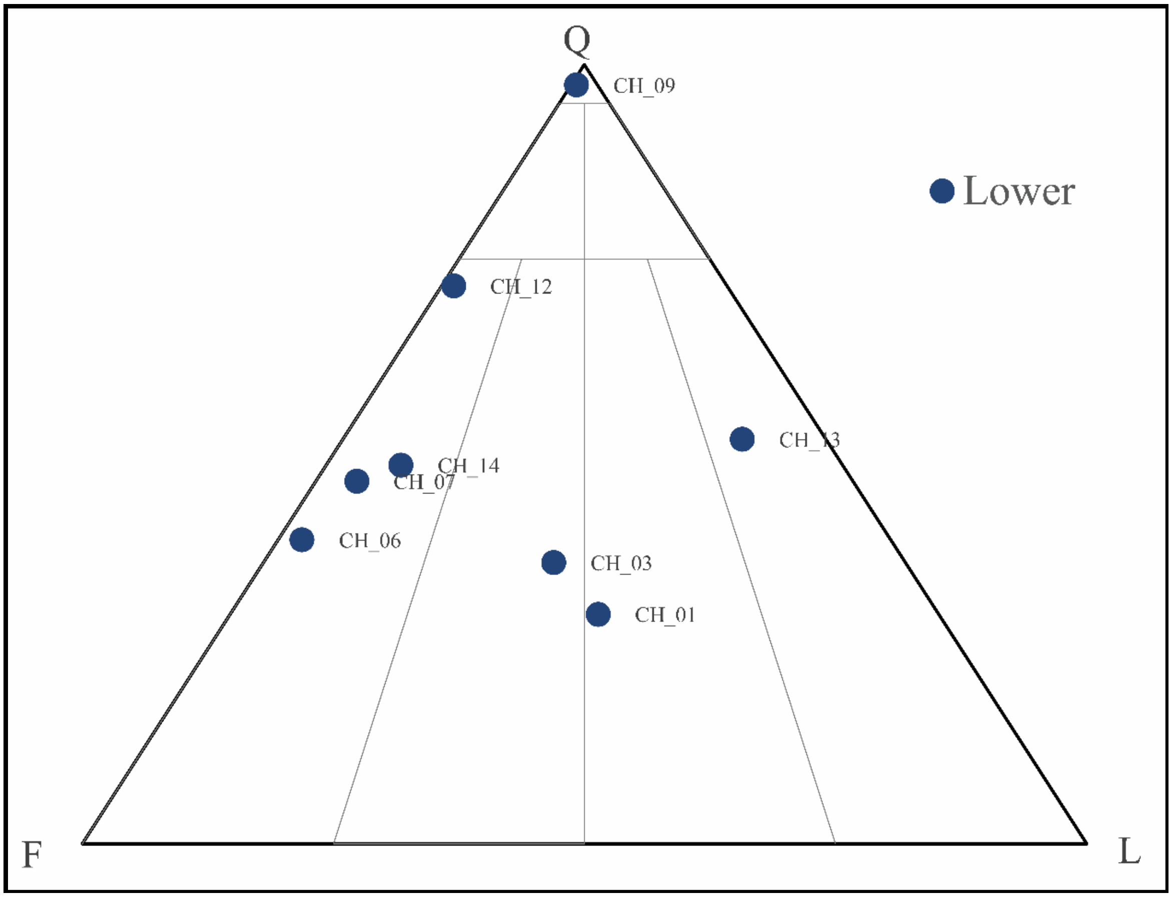

Figure 36.-[QFL Folk diagram of the Lower Chota Member sandstone samples. Classification of sandstones are in the triangular diagram QFL from Folk (1956) (Fig. 23.B). Blue dots represent the Lower Chota Member samples. Key: Quartz content (Q). Feldspar content (F). Lithic content (L). Total samples, n = 08.]

Middle Chota Member QFL Folk diagram (Fig. 39) shows twenty-two (14) samples. The position of each sample represents a specific classification name. From bot to top, Middle Chota Member generate the following results: CH_18 (Arkose), CH_24 (Arkose), CH_25 (Feldspathic Litharenite), CH_27 (Subarkose), CH_31 (Feldspathic Litharenite), CH_33 (Arkose), CH_34 (Arkose), CH_35 (Subarkose), CH_36 (Subarkose), CH_38 (Arkose), CH_39 (Arkose), CH_40 (Subarkose), CH_41 (Arkose), and CH_43 (Feldspathic Litharenite).

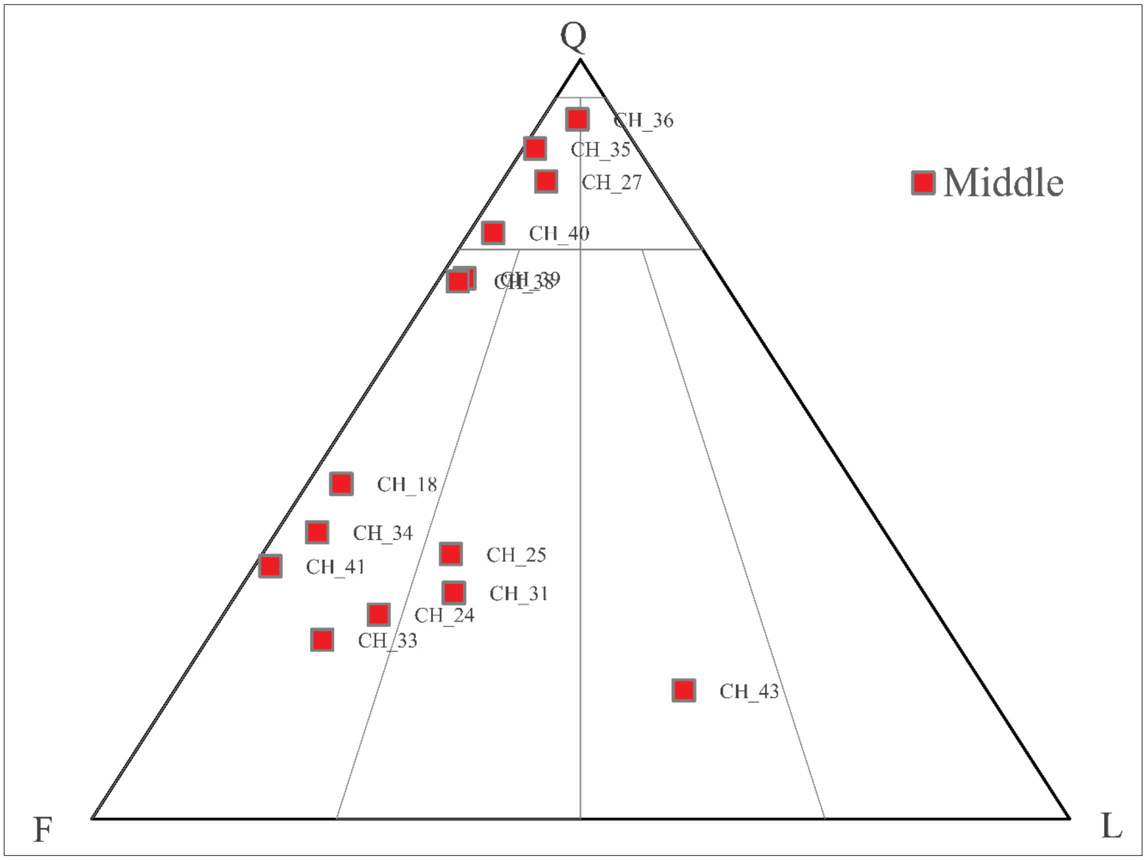

Figure 37.-[QFL Folk diagram of the Middle Chota Member sandstone samples. Classification of sandstones are in the triangular diagram QFL from Folk (1956) (Fig. 23.B). Red squares represent the Middle Chota Member samples. Key: Quartz content (Q). Feldspar content (F). Lithic content (L). Total samples, n = 14.]

Also, a QFL Folk diagram showing the average value of the Middle Chota Member and the average value of the Lower Chota Member sandstone samples was developed (Fig. 40). The average of the Lower Chota Member sandstone samples and the average of the Middle Chota Member sandstone samples describes Lithick Arkose sediments.

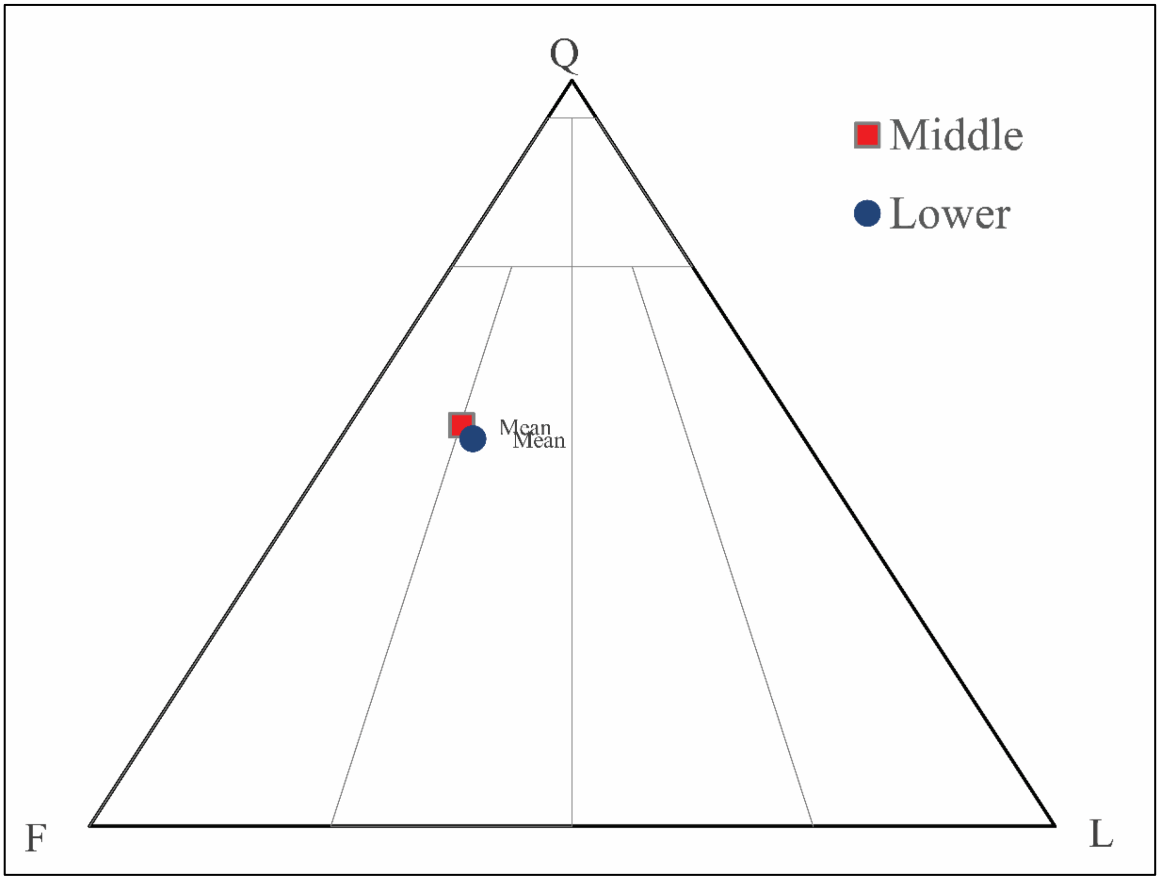

Figure 38.-[QFL Folk diagram showing the average value of the Middle Chota Member and the average value of the Lower Chota Member sandstone samples. Classification of sandstones are in the triangular diagram QFL from Folk (1956) (Fig. 23.B). Red square represents the average value from 14 samples of the Middle Chota Member. Blue dot represents the average value from 08 samples of the Lower Chota Member samples. Key: Quartz content (Q). Feldspar content (F). Lithic content (L). Total samples, n = 08.]

In terms of provenance of the arenites from the Chota Unit, both units, Lower Chota Member and Middle Chota Member, fall in the field corresponding to Recycled Orogenic defined by Dickinson (1985), between and dissected Volcanic arc and Basement uplift and Transitional continental (Fig. 41). Then, the clastic sandy demi-consolidated sediments analyzed from the Lower and Middle Chota members became from the recycling of a rhyolitic and dacitic volcanic arc volcaniclastics (reworked pyroclastic flows, fall-outs and volcanic lithic fragments), and from a basement uplift and transitional continental composed by a metamorphic orogen, the metamorphic Eastern Cordillera of Ecuador, and the substratum in the area, the Guamote metamorphic unit.

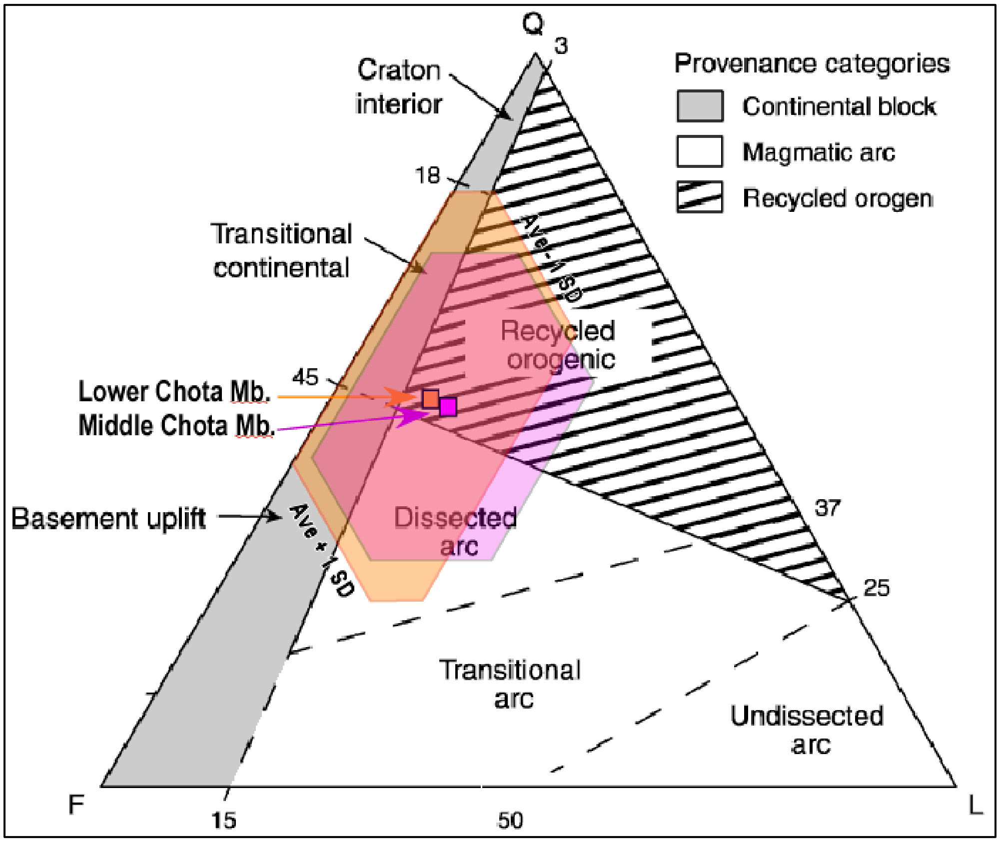

Figure 39.-[Provenance of sandstones of the Lower Chota Member and Middle Chota Member showing the compositional fields of tectonic provenance defined with the triangular diagram after Dickinson (1985). Key: Ave, average of composition or Mean; SD, standard deviation of a population of samples. n: total number of samples analyzed, n=12 samples for the Lower Chota Mb, and n=08 samples for Middle Chota Mb.]

4.4. X-Ray Diffraction Pattern Generation Results

Nineteen (19) mudstones were collected and prepared for the X-Ray Diffraction (XRD) analysis technique (Table 03). From this group of 19 samples, 08 samples correspond to the Lower Chota Member and 11 samples correspond to the Middle Chota Member.

Table 3.-[X-Ray Diffraction samples in stratigraphic log. "Chemistry Laboratory Name" represents the name for the (X, Y) pair data base developed for the Chemistry Laboratory of Characterization of materials, of the School of Chemical Sciences and Engineering, at Yachay Tech University. "Chemistry Variable Name" Name used for label the mud samples in the chemistry lab before X-Ray Diffraction analysis. "Sample Name" represents the name assigned on field at the moment of collect the sample. "Variable Name" is the name assigned for the study. Samples are represented in stratigraphic order from bottom to top.]

Member	***Chemistry Laboratory Name***	***Chemistry Variable Name***	***Sample Name***	***Variable Name***
Middle	*DRX_ZM_23_0173*	*14 MH*	*MH_14x*	*CH_42*
Middle	*DRX_ZM_23_0176*	*17 MH*	*MJ6_03*	*CH_37*
Middle	*DRX_ZM_23_0177*	*18 MH*	*230207.5*	*CH_32*

Member	Chemistry Laboratory Name	Chemistry Variable Name	Sample Name	Variable Name
Middle	*DRX_ZM_23_0180*	*21 MH*	*230207.3b*	*CH_30*
Middle	*DRX_ZM_23_0179*	*20 MH*	*230207.3a*	*CH_29*
Middle	*DRX_ZM_23_0178*	*19 MH*	*230207.2*	*CH_28*
Middle	*DRX_ZM_23_0175*	*16 MH*	*MH_16x*	*CH_23*
Middle	*DRX_ZM_23_0174*	*15 MH*	*MH_15x*	*CH_22*
Middle	*DRX_ZM_23_0192*	*12 MH*	*MH_34_22*	*CH_21*
Middle	*DRX_ZM_23_0191*	*11 MH*	*MH_33_22*	*CH_20*
Middle	*DRX_ZM_23_0190*	*10 MH*	*MH_32_22*	*CH_19*
Lower	*DRX_ZM_23_0188*	*8 MH*	*MH_30_22*	*CH_17*
Lower	*DRX_ZM_23_0187*	*7 MH*	*MH_29_22*	*CH_16*
Lower	*DRX_ZM_23_0184*	*4 MH*	*MH_20_21*	*CH_11*
Lower	*DRX_ZM_23_0183*	*3 MH*	*MH_19_21*	*CH_10*
Lower	*DRX_ZM_23_0182*	*2 MH*	*MH_18_21*	*CH_08*
Lower	*DRX_ZM_23_0181*	*1 MH*	*MH_17_21*	*CH_06*
Lower	*DRX_ZM_23_0185*	*5 MH*	*MH_24_21*	*CH_05*
Lower	*DRX_ZM_23_0186*	*6 MH*	*MH_27_21*	*CH_02*

To interpret the results of the X-Ray Diffraction analysis it was necessary to create X-Ray Diffraction Pattern graphic for each analyzed sample. (Annex 4, Fig. 48 and Fig. 49). The graphics are a result of "Match!" Phase Analysis, using Powder Diffraction Software (version 3.15 build 258 for Windows 64-bit, Putz Holger, 2003-2023, Crystal Impact, Bonn, Germany). In the X-Ray Diffraction Pattern graphics of the West Chota Formation is possible to identify: kaolinite, montmorillonite, vermiculite, halloysite, illite, palygorskite, sepiolite, and chlorite clay minerals (Table 04). To consider a value for clay mineral is necessary to select the highest peak value of the X-Ray Diffraction Pattern graphic.

Table 4.-[Peak values for clay minerals identified in the X-Ray Diffraction Pattern graphics of the West Chota Formation. At the top of the table, from right to left; "Variable Name" or the Sample ID, after it there is the name of clay minerals founded. Samples are represented in stratigraphic order from bottom to top. Lower Chota Samples ID in red. Middle Chota Samples ID in blue.]

Variable Name	Kaolinite	Morntmorillite	Vermiculite	Halloysite	Illite	Palygorskite	Sepiolite	Chlorite
CH_42	*475*	*475*	*75*	*150*	*100*	*1000*	*20*	*750*
CH_37	*400*	*175*	*500*	*200*	*1000*	*575*	*0*	*650*
CH_32	*150*	*125*	*0*	*50*	*300*	*900*	*0*	*700*

Variable Name	*Kaolinite*	*Morntmorillite*	*Vermiculite*	*Halloysite*	*Illite*	*Palygorskite*	*Sepiolite*	*Chlorite*
CH_30	*260*	*280*	*0*	*150*	*1000*	*400*	*0*	*500*
CH_29	*300*	*300*	*0*	*100*	*850*	*1000*	*10*	*885*
CH_28	*350*	*225*	*25*	*40*	*325*	*800*	*0*	*460*
CH_23	*250*	*300*	*175*	*100*	*900*	*850*	*0*	*650*
CH_22	*300*	*250*	*0*	*90*	*650*	*1000*	*25*	*750*
CH_21	*225*	*225*	*0*	*75*	*150*	*1000*	*50*	*350*
CH_20	*400*	*75*	*0*	*140*	*400*	*425*	*875*	*50*
CH_19	*80*	*100*	*0*	*50*	*350*	*450*	*0*	*150*
CH_17	*240*	*250*	*0*	*50*	*350*	*850*	*0*	*750*
CH_16	*190*	*300*	*150*	*90*	*875*	*850*	*0*	*450*
CH_11	*40*	*300*	*0*	*200*	*875*	*975*	*0*	*550*
CH_10	*160*	*190*	*0*	*25*	*150*	*650*	*10*	*450*
CH_08	*300*	*0*	*200*	*90*	*750*	*850*	*0*	*875*
CH_06	*150*	*180*	*0*	*50*	*560*	*850*	*0*	*480*
CH_05	*360*	*275*	*175*	*195*	*175*	*725*	*0*	*550*
CH_02	*150*	*0*	*115*	*100*	*140*	*850*	*10*	*700*

Data normalization is an important preprocessing step that can improve the quality and reliability of subsequent analysis and modeling efforts. For that reason, after generate the Peak Values Table (Table 04) also was necessary to create a Normalized Peak Values Table (Table 05) to perform the representation of bar diagram figures.

Table 5.-[Normalized peak values for clay minerals identified in the X-Ray Diffraction Pattern graphics of the West Chota Formation. At the top of the table, from right to left; "Variable Name" or the Sample ID, after it there is the name of clay minerals founded. Samples are represented in stratigraphic order from bottom to top. Lower Chota Samples ID in red. Middle Chota Samples ID in blue.]

Variable Name	*Kaolinite*	*Morntmorillite*	*Vermiculite*	*Halloysite*	*Illite*	*Palygorskite*	*Sepiolite*	*Chlorite*
CH_42	*15.60*	*15.60*	*2.46*	*4.93*	*3.28*	*32.84*	*0.66*	*24.63*
CH_37	*11.43*	*5.00*	*14.29*	*5.71*	*28.57*	*16.43*	*0.00*	*18.57*
CH_32	*6.74*	*5.62*	*0.00*	*2.25*	*13.48*	*40.45*	*0.00*	*31.46*
CH_30	*10.04*	*10.81*	*0.00*	*5.79*	*38.61*	*15.44*	*0.00*	*19.31*
CH_29	*8.71*	*8.71*	*0.00*	*2.90*	*24.67*	*29.03*	*0.29*	*25.69*
CH_28	*15.73*	*10.11*	*1.12*	*1.80*	*14.61*	*35.96*	*0.00*	*20.67*
CH_23	*7.75*	*9.30*	*5.43*	*3.10*	*27.91*	*26.36*	*0.00*	*20.16*
CH_22	*9.79*	*8.16*	*0.00*	*2.94*	*21.21*	*32.63*	*0.82*	*24.47*

Variable Name	*Kaolinite*	*Morntmorillite*	*Vermiculite*	*Halloysite*	*Illite*	*Palygorskite*	*Sepiolite*	*Chlorite*
CH_21	*10.84*	*10.84*	*0.00*	*3.61*	*7.23*	*48.19*	*2.41*	*16.87*
CH_20	*16.91*	*3.17*	*0.00*	*5.92*	*16.91*	*17.97*	*37.00*	*2.11*
CH_19	*6.78*	*8.47*	*0.00*	*4.24*	*29.66*	*38.14*	*0.00*	*12.71*
CH_17	*9.64*	*10.04*	*0.00*	*2.01*	*14.06*	*34.14*	*0.00*	*30.12*
CH_16	*6.54*	*10.33*	*5.16*	*3.10*	*30.12*	*29.26*	*0.00*	*15.49*
CH_11	*1.36*	*10.20*	*0.00*	*6.80*	*29.76*	*33.16*	*0.00*	*18.71*
CH_10	*9.79*	*11.62*	*0.00*	*1.53*	*9.17*	*39.76*	*0.61*	*27.52*
CH_08	*9.79*	*0.00*	*6.53*	*2.94*	*24.47*	*27.73*	*0.00*	*28.55*
CH_06	*6.61*	*7.93*	*0.00*	*2.20*	*24.67*	*37.44*	*0.00*	*21.15*
CH_05	*14.66*	*11.20*	*7.13*	*7.94*	*7.13*	*29.53*	*0.00*	*22.40*
CH_02	*7.26*	*0.00*	*5.57*	*4.84*	*6.78*	*41.16*	*0.48*	*33.90*

As a bar diagram expresses graphically the mineral abundance of clay minerals. In this study, bar diagrams from normalized clay minerals peak values identified in the X-Ray Diffraction Pattern Graphics of the West Chota Formation in the Lower Chota Member and the Middle Chota Member samples were developed (Fig. 42).

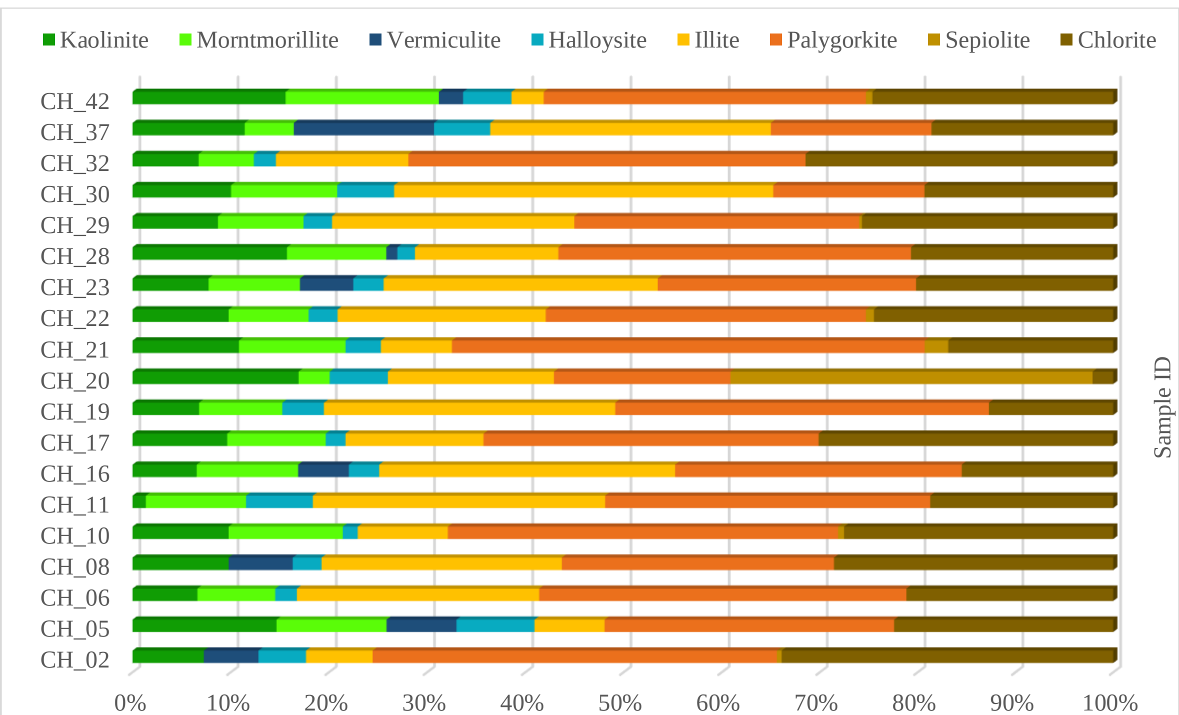

Figure 40.-[X-Ray Diffraction bar diagram results of the 19 claystone samples from the Lower Chota Member and the Middle Chota Member of the West Chota Formation. Samples are represented in stratigraphic order from bottom to top.]

Following the results of the mineral abundance for clay minerals of the Lower Chota Member, this study found diagnostic minerals as: kaolinite, montmorillonite, vermiculite, halloysite, illite, palygorskite, sepiolite, chlorite (Fig. 43).

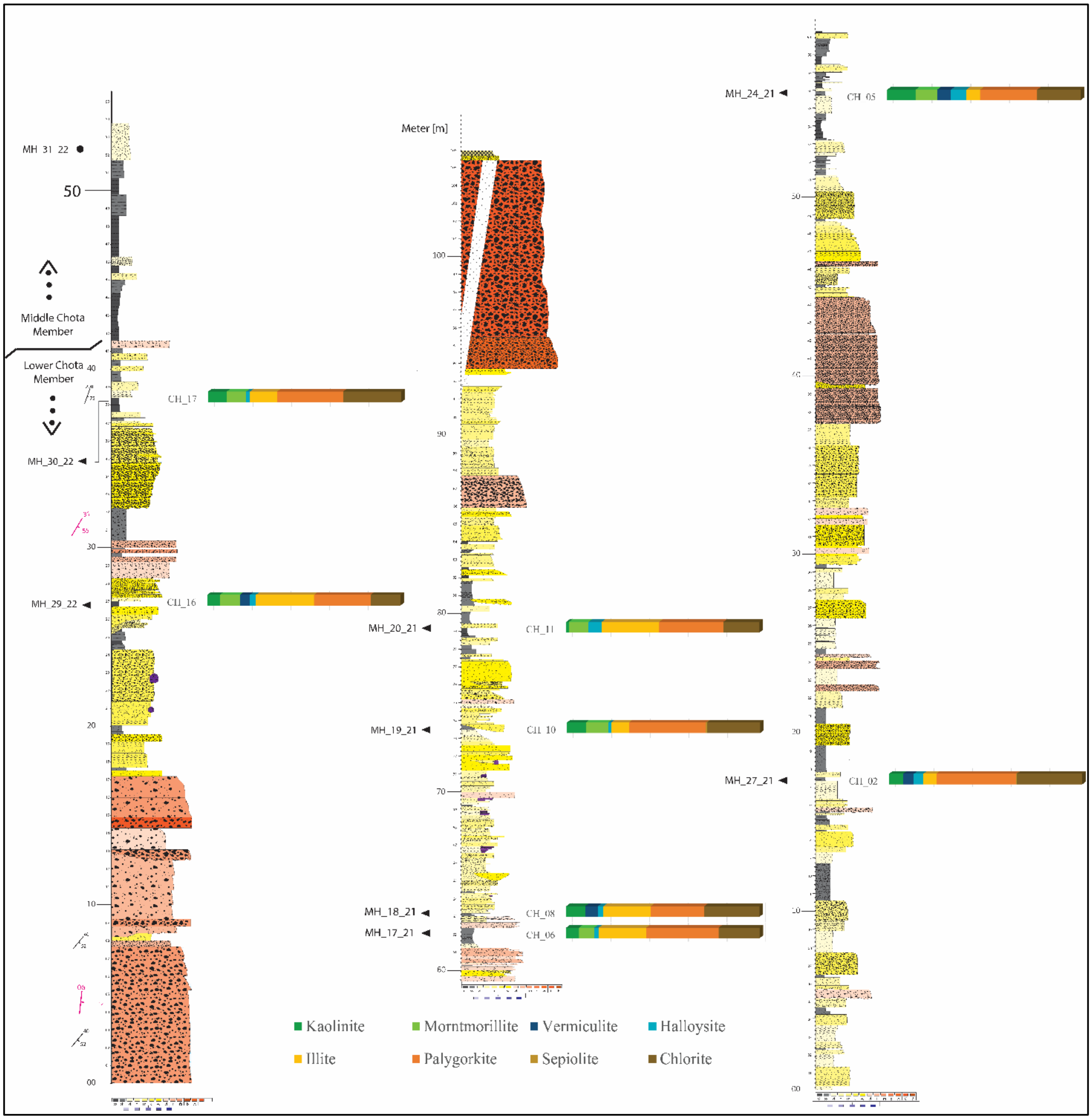

Figure 41.-[Proposed Lower Chota Member stratigraphic column with clay mineral abundance (Table 05). Black triangles represent samples used in XRD studies. Stratigraphic Log is reduced 15% of the 1:50 original recorded scale.]

Following the results of the mineral abundance for clay minerals of the Middle Chota Member, this study found diagnostic minerals as: kaolinite, montmorillonite, vermiculite, halloysite, illite, palygorskite, sepiolite, chlorite (Fig. 44).

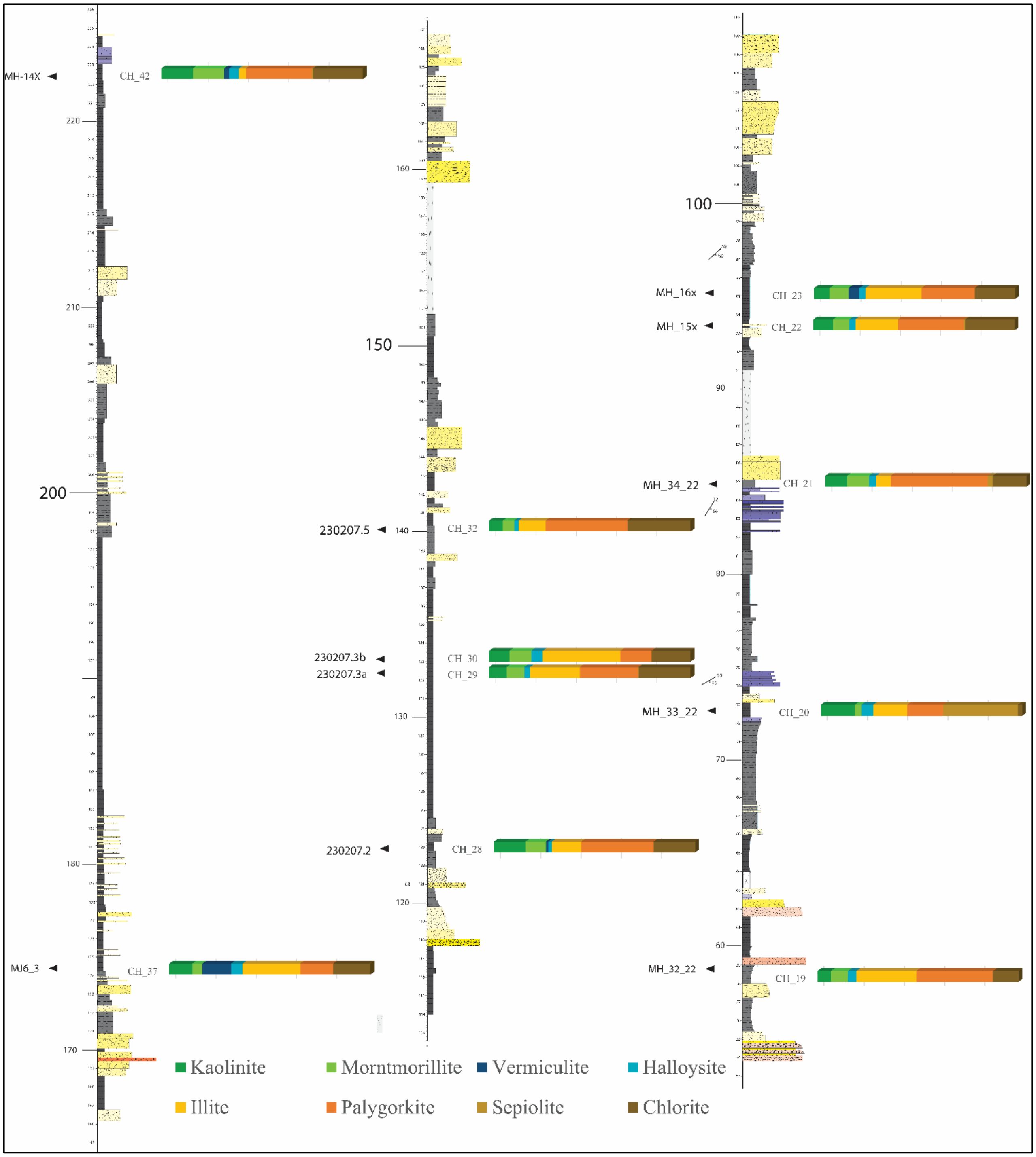

Figure 42.-[Proposed Middle Chota Member stratigraphic column with clay mineral abundance (Table 05). Black triangles represent samples used in XRD studies. Stratigraphic Log is reduced 15% of the 1:50 original recorded scale.*]*

This study allowed to obtain a consolidated analysis of the Lower Chota Member and Middle Chota Member, exhibiting similarities in their clay mineral compositions, suggesting similar environmental conditions during deposition with slightly variations.

4.5. Structural Cross Section

Even though the main objective of this work was to analyze and interpret the stratigraphy and sedimentary processes in the West Chota Formation, a general geological map (Fig. 24) was created. Geological map shows the distribution of the stratigraphic units (members) in the study area. Strike and dip all strata have mostly southwest to northeast direction. The lowermost part of Chota Formation is the Lower Chota Member, its present overturned strata. Follow by the Middle Chota Member and Upper Chota Member showing normal way up direction, but folded and faulted. These members are cover by an Alluvial Fan Deposits unit and overlayed by a Fluvial Terraces unit. Finally, there is a pink line Northwest-Southeast direction which represent the profile section in which is performed the structural cross section (Fig. 45).

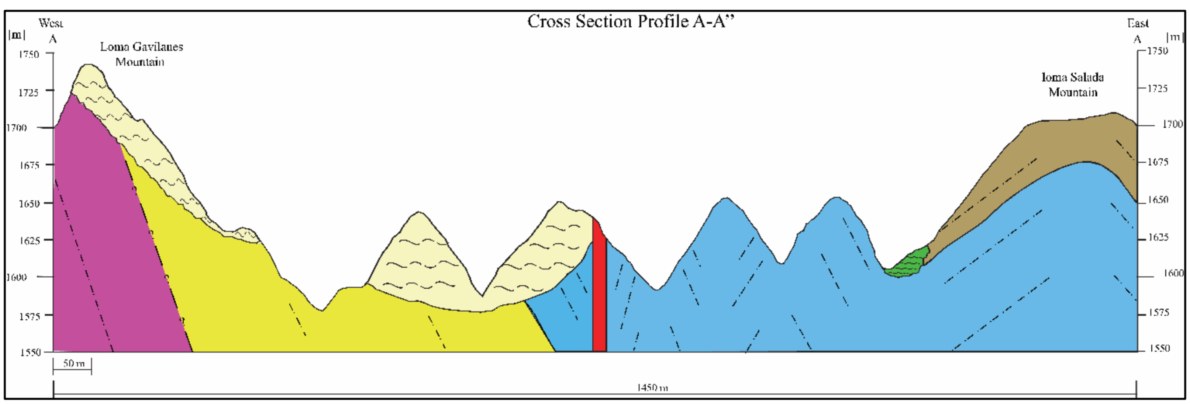

Figure 43.-[Structural Cross Section A-A'' (Pink line at Fig. 25). "Y" axis scale is amplified by 2 times the "X" axis scale. Data was extrapolated using stratigraphic thickness and measured altitudes.]

CHAPTER 5. DISCUSSION

The Chota Formation lithologies in the study area, from bottom to top are: Lower Chota Member, Middle Chota Member, Upper Chota Member, Gavilanes Breccia, Alluvial Fan Deposits Unit, and Fluvial Terraces Unit. At the beginning of the work, was presented the different stratigraphic models by Barragán et al, (1996) and Winckler et al (2005) about the Chota Unit or the Chota West Formation respectively of the Chota basin. On the one hand, Barragán et al., (1996) indicate that the Chota Basin stratigraphic sequence was represented by four principal units (from bottom to top: Chota unit, Santa Rosa Unit, Peñas Coloradas Unit, and Carpuela Unit). On the other hand, Winkler et al. (2005) indicate that the Chota Formation stratigraphic sequence was represented by three principal units (from bottom to top): Peñas Coloradas Formation, Chota Formation (subdivide in Chota West and Chota East by a lahar), and Santa Rosa Unit. The fieldwork carried out allowed this study to analyze the rocks and structures of the western part of the Chota basin at the Chota Formation (Chota Lower Member, Middle Chota Member, and Upper Chota Member), previous known as the Chota Formation and the Santa Rosa Formation.

The studied sequences of the western Chota Formation are subdivided into three new members; however, it is possible to identify dominant lithologies on each of it. The Lower Chota Member, conglomeratic and sandy facies of braided stream river (BSR) being overlying (in retrogradation) by sandy to silty and shaly facies of Delta front and Delta plain, organized in minor orders as prograding beds parasequences (*sensu* Van Wagoner et al., 1990). The Middle Chota Member, conglomeratic sediments, limestones, muddy with sandy sediments with facies from mainly the Middle shelf, organized apparently in an aggrading style. The presence of roots, gastropods and bivalves in the fossils record are important markers characteristics of this member. Finally, the Upper Chota Member, with lacustrine facies composed of multi-colored gray, pink, cream, and brown, coarsening-upper, claystones and siltstones. The interplay of facies, environments and all clastic and fossiliferous calcareous lithologies occurring in the Lower Chota Member and the Middle Chota Member support the interpretation that, during Late Miocene to early lower Pliocene times. Also, there is evidence of Alluvial Fan Deposits with conglomeratic sequence and Fluvial Terraces units that need to be studied in detail.

By analyzing the attributes of the sedimentary rocks outcropping in the study area, such as: grain size, sorting, roundness, composition, polarity, lateral and vertical tendencies, primary and secondary structures, the study defines facies and environments of deposition. This information helps us understand the sedimentary processes that formed the rocks and how they were deposited, such as river distal alluvial facies, fluvial channel facies, delta facies, shelf lacustrine facies, etc. The occurrence of minerals and lithic fragments in the Lower Chota Member evidences the functioning of a contemporaneous acid to intermediate volcanic source, producing medium to very fine-grained volcanic grains, releasing to the atmosphere rhyolitic to dacitic products, ulteriorly reworked in medium to very fine-grained sandstones. However, for the Middle Chota Member, the occurrence of minerals and lithic fragments evidences the contemporaneous functioning of an acid to intermediate volcanic source, producing fine to very fine-grained volcanic grains, releasing to the atmosphere rhyolitic products, reworked inside the basin in fine to very fine-grained sandstones and silty sandstones. In terms of provenance of the arenites, both units, the clastic sandy demi-consolidated sediments from the Lower Chota Member and the Middle Chota member became from the recycling of a rhyolitic and dacitic volcanic arc, also from a basement uplift and transitional continental composed by a metamorphic orogen.

Comparing the mineral abundances of the Middle Chota Member (Fig. 42), there is a range of clay minerals. This results in kaolinite (ranging from 6.78% to 16.91), montmorillonite (range from 3.17% to 15.60%), vermiculite (range from 0.00% to 14.29%), halloysite (range from 1.80% to 5.92%), illite (range from 7.23% to 38.61%), palygorskite (range from 15.44% to 48.19%), sepiolite (range from 0.00% to 37.00%), and chlorite (range from 2.11% to 31.46%). Moreover, comparing the mineral abundances of the Lower Chota Member (Fig. 42), there is a range in clay minerals, resulting in kaolinite (range from 0.00% to 14.66%), montmorillonite (range from 0.00% to 11.62%), vermiculite (range from 0.00% to 7.13%), halloysite (range 1.53% to 7.94%), illite (range from 6.78% to 30.12%), palygorskite (range from 29.53% to 41.16%), sepiolite (range from 0.00% to 0.61%), chlorite (21.15% to 33.90%). Overall, while both members exhibit similarities in certain clay mineral abundances, there are also notable differences, particularly in the sepiolite, illite, and palygorskite abundance clay ranges. These differences could reflect variations in depositional environments or geological processes between the Middle Chota Member and the Lower Chota Member.

When comparing clay mineral compositions with dry/humid conditions for both members, it is necessary to consider the characteristics of clay minerals with them. In general, kaolinite and halloysite are often associated with humid conditions. Illite and montmorillonite can occur in both humid and dry environments. Palygorskite, Sepiolite, and Chlorite are clay mineral indicators for arid or semi-arid regions or dry conditions (Fonseca. E., 2019, and Singer, 1984). Analyzing the mean values of the clay mineral abundance of the Lower Chota Member and Middle Chota Member based on the characteristics of clay minerals associated with different environmental conditions, comparisons can be drawn between the average values of each clay mineral for the middle and lower Chota members.

In the Middle Chota member, potentially experiencing more humid conditions, a moderate presence of clay minerals associated with humid environments is observed. Kaolinite and halloysite, indicative of humidity, show moderate presence, suggesting the influence of moisture in the region. Illite and montmorillonite, capable of occurring in both humid and dry environments, also exhibit significant presence, indicating a mixed environmental setting. Furthermore, the significant presence of clay minerals, such as palygorskite and chlorite, associated with drier conditions suggests that despite potential humidity, the region may also experience periods of aridity or semi-aridity. In contrast, the Lower Chota member, potentially characterized by drier conditions, shows similar patterns of clay mineral presence compared to the middle member but with some variations in proportions. While kaolinite and halloysite still exhibit moderate presence, indicating some humidity influence, the presence of illite and montmorillonite remains significant, suggesting a mixed environmental setting similar to the middle member. Notably, the lower Chota member shows slightly higher proportions of clay minerals associated with drier conditions, such as palygorskite, sepiolite, and chlorite, suggesting a relatively drier environment than the middle member. Finally, the study highlights similarities in clay mineral compositions between the two members but also indicates potential differences in prevailing environmental conditions, with the lower Chota member showing slightly higher proportions of clay minerals indicative of drier conditions.

CHAPTER 6. CONCLUSIONS

During the thesis research project, I created a general geologic map of the West Chota Formation. Based on the field observations West Chota Formation was subdivide into three (3) members: Lower Member, Middle Member and Upper Member. The new subdivision of the West Chota Formation allowed the better understanding and compression about the stratigraphy of the area and its paleocondition implications. After determining: the general geologic map, the stratigraphic model, the descriptions of the sediments, the structural cross section, the petrographically and XRD characterization It is possible to conclude that the Chota Formation is stratigraphically above Gavilanes Breccias and over it an unconformity of Alluvial Fan deposit.

One objective of the present work was to determine the stratigraphy sequence for the lacustrine and fluvial sediments between “Loma Salada” and “Loma Gavilanes” mountains. After construct the proposed stratigraphic logs for the Lower Chota Member and the Middle Chota Member. Is possible to conclude that the evolution of the Lower Chota Member shows a vertical variation from conglomerates to sandstones and siltstones organized in retrograding sequences at major order with facies from Alluvial fan, Braided stream rivers, distal Fluvial, and proximal Delta facies, interbedded with reworked sediments (debris flows, DF), and some volcanic deposits. The Middle Chota Member shows a vertical variation from sandstones, siltstones, fossiliferous limestones, claystones, and shales organized in retrograding sequences at major order up to Lacustrine middle shelf facies, including probably a shaly maximum flooding surface. The Upper Chota Member, not studied in detail here, are composed by mudstones and sandstones probably lacustrine deposits. Finally, the facies, environments and lithologies within the Lower Chota Member and the Middle Chota Member testify the latest living period, during Late Miocene to early lower Pliocene times, of the westernmost part of the interior lacustrine setting before the activation of Andean uplifting (the Eastern Cordillera of Ecuador), contemporaneous of one of the most intensive Andean growing periods.

The petrographic results (occurrence of minerals and lithic fragments), obtained analyzing sandy samples under the binocular microscope allow to conclude that, there is evidences of the functioning of a contemporaneous volcanic source for Lower Chota member and the Middle Chota Member: (1) Acid to intermediate for the Lower Chota Member, producing medium to very fine-grained volcanic grains, releasing to the atmosphere rhyolitic to dacitic products, reworked after in medium to very fine-grained sandstones; and (2) acid to intermediate volcanic source for the Middle Chota Member, producing fine to very fine-grained volcanic grains, releasing to the atmosphere rhyolitic products, reworked inside the basin in fine to very fine-grained sandstones and silty sandstones. In terms of composition of sandstones: (1) the Lower Chota Member shows a variable composition, mainly composed of arkoses and lithic-arkoses, with low to moderate content of Quartz; and (2) the Middle Chota Member shows a composition, of sub-arkoses, arkoses and felspathic litharenites.

The X-Ray Diffraction claystone analysis recovered from the Lower Chota Member and from the Middle Chota Member allow us to conclude that there are two types of characteristic climates in sedimentary series analysis: dry and humid. Both members (Lower and Middle) show characteristics of transitional climates, but with a tendency to have drier climate (with the occurrence of Palygorskite, Sepiolite, and Chlorite clays) than humid climate (Kaolinite and Vermiculite), been unexpected considering the results of (Fonseca, 2021) with humid results in the eastern Chota unit.

CHAPTER 7. REFERENCES

Aspden, J. A., Harrison, S. H., & Rundle, C. C. (1992). New geochronological control for the tectono-magmatic evolution of the metamorphic basement, Cordillera Real and El Oro Province of Ecuador. Journal of South American Earth Sciences, 6(1–2), 77–96. https://doi.org/10.1016/0895-9811(92)90019-U

Aspden, J. A., & Litherland, M. (1992). The geology and Mesozoic collisional history of the Cordillera Real, Ecuador. Tectonophysics, 205(1–3), 187–204. https://doi.org/10.1016/0040-1951(92)90426-7

Baby, P., Rivadeneira, M., Barragán, R., & Christophoul, F. (2013). Thick-skinned tectonics in the Oriente foreland basin of Ecuador. Geological Society Special Publication, 377(1), 59–76. https://doi.org/10.1144/SP377.1

Barragán, R., Baudino, R., & Marocco, R. (1996). Geodynamic evolution of the Neogene intermontane Chota basin, Northern Andes of Ecuador. Journal of South American Earth Sciences, 9(5–6), 309–319. https://doi.org/10.1016/s0895-9811(96)00016-8

Barragán, R., Christophoul, F., White, H., Baby, P., Rivadeneira, M., Ramirez, F., & Rodas, J. (2004). Estratigraphia secuencial del Cretacio de la Cuenca Oriente del Ecuador. In La Cuenca Oriente: Geología y Petróleo (Vol. 144, pp. 46–68). Institut français d'études andines. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/doc34-08/010036207.pdf

Boschman, L. M. (2021). Andean mountain building since the Late Cretaceous: A paleoelevation reconstruction. Earth-Science Reviews, 220. https://doi.org/10.1016/j.earscirev.2021.103640

Burgos J.D., Christophoul F., Baby P., Antoine P.-O., Soula J.-C., Good D., and Rivadeneira M., (2005), Dynamic evolution of Oligocene - Neogene sedimentary series in a retroforeland basin setting: Oriente Basin, Ecuador: 6th International Symposium on Andean Geodynamics (6ISAG), Sept. 11-14, 2005, Barcelona-Spain, Extended Abstracts, pp. 127-130, Barcelona.

Cadena E.A., and Casado-Ferrer I., (2019), Late Miocene freshwater mussels from the intermontane Chota Basin,northern Ecuadorian Andes: Journal of South American Earth Sciences 89 (2019) 39–46, https://doi.org/10.1016/j.jsames.2018.10.012

Catuneanu, O. (2006). Principles of Sequence Stratigraphy (First Edit, Issue 1). Elsevier B.V. http://www.science.earthjay.com/instruction/HSU/2015_fall/GEOL_332/PRINCIPLES_OF_Sequence_Stratigraphy.pdf

Cediel, F., & Shaw, R. P. (2019). Geology and Tectonics of Northwestern South America. In Springer. Springer Nature Switzerland AG 2019. http://link.springer.com/10.1007/978-3-319-76132-9

Christophoul, F., Baby, P., & Dávila, C. (2002). Stratigraphic responses to a major tectonic event in a foreland basin: The Ecuadorian Oriente Basin from Eocene to Oligocene times. Tectonophysics, 345(1–4), 281–298. https://doi.org/10.1016/S0040-1951(01)00217-7

Coltorti, M., & Ollier, C. D. (2000). Geomorphic and tectonic evolution of the Ecuadorian Andes. Geomorphology, 32(1–2), 1–19. https://doi.org/10.1016/S0169-555X(99)00036-7

Dickinson W.R., (1985), Interpreting provenance relations from detrital modes of sandstones: In: G.G. Zuffa Ed., Provenance of Arenites, Proceedings of the NATO ASI on Reading Provenance of Arenites, Cetraro, Cosenza – Italy, June 03-11, 1984, Reidel Publishing Co., pp. 333-362, Holland.

Eguez, A., and Beate, B. 1992 Estratigrafía y tectónica de la cuenca intramontañosa del Chota. Il Jornadas en Ciencias de la Tierra, Resúmenes, Escuela Politécnica Nacional (EPN) eds., pp. 131–144, Quito.

Einsele, G. (2000). SEDIMENTARY BASINS (Second Edi). Springer-Verlag Berlin Heidelberg GmbH. https://doi.org/10.1007/978-3-662-04029-4

Fonseca, E. (2021). Sedimentological and paleoenvironmental study of the Peñas Coloradas Formation of the Chota basin , Ecuador.

Ford M., Williams A.D., Malartre F., and Popescu S.M., (2007), Stratigraphic architecture, sedimentology and structure of the Vouraikos Gilbert-type fan delta, Gulf of Corinth, Greece: In: Sedimentary Processes, Environments and Basins: A Tribute to Peter Friend Edited by Gary Nichols, Ed Williams and Chris Paola, 2007 International Association of Sedimentologists, SP 38, pp. 50 -90, ISBN: 978-1-405-17922-5.

Garzanti E., (2019), Petrographic classification of sand and sandstone: Earth-Science Reviews, Volume 192, 2019, Pages 545-563, ISSN 0012-8252, https://doi.org/10.1016/j.earscirev.2018.12.014

Gutiérrez, E. G., Horton, B. K., Vallejo, C., Jackson, L. J., & George, S. W. M. (2019). Provenance and geochronological insights into Late Cretaceous-Cenozoic foreland basin development in the Subandean Zone and Oriente Basin of Ecuador. In Andean Tectonics (pp. 237–268). Elsevier Inc. https://doi.org/10.1016/B978-0-12-816009-1.00011-3

Hoke G.D., Giambiagi L.B., Garzioni C.N., Mahoney J.B., and Strecker M.R., (2014), Neogene paleoelevation of intermontane basins in a narrow, compressional mountain range, southern Central Andes of Argentina: Earth and Planetary Science Letters, Volume 406, 15 November 2014, Pages 153-164, https://doi.org/10.1016/j.epsl.2014.08.032

Huff, W., & Reynolds, C. (1990). Book Review. Clays and Clay Minerals, 38(4), 448.

Hughes, R. A., & Pilatasig, L. F. (2002). Cretaceous and Tertiary terrane accretion in the Cordillera Occidental of the Andes of Ecuador. Tectonophysics, 345(1–4), 29–48. https://doi.org/10.1016/S0040-1951(01)00205-0

Hughes, R. A., & Pilatasig, L.F. (2002). Cretaceous and Tertiary terrane accretion in the Cordillera Occidental of the Andes of Ecuador. Tectonophysics, 345(1–4), 29–48. https://doi.org/10.1016/S0040-1951(01)00205-0

Hungerbuhler, D., Steinmann, M., & Winkler, W. (1995). An integrated study of fill and deformation in the Andean intermontane basin of Nabón (Late Miocene), southern Ecuador. Sedimentary Geology, 96(3–4), 257–279. https://doi.org/10.1016/0037-0738(94)00137-j

Jaillard, E., Caron, M., Dhondt, A., Ordoñez, M., Andrade, R., Bengtson, P., Bulot, L., Cappetta, H., Dávila, C., Díaz, R., Lascano, M., Huacho, J., Huamá, C., Darwin, J., Jiménez, N., Montenegro, J., Néraudeau, D., Rivadeneira, M., Toro Álava, J., … Zambrano, I. (1997). Síntesis estratigráfica y sedimentológica del Cretáceo y Paleógeno de la cuenca oriental del Ecuador. Orstom-Petroproduccion, 164.

Jaillard, E., Ordóñez, M., Suárez, J., Toro Álava, J., Iza, D., & Lugo, W. (2004). Stratigraphy of the Late Cretaceous-Paleogene deposits of the Western Cordillera Ecuador : Geodynamic implications. Journal of South American Earth Sciences, 17, 49–58. https://hal.archives-ouvertes.fr/hal-00101729

Jaillard E., Lapierre H., Ordóñez M., Toro Álava J., Amórtegui A., & Vanmelle J., (2009), Accreted oceanic terranes in Ecuador: southern edge of the Caribbean Plate?: Geological Society Special Publication 328: 469-485, London, doi:10.1144/SP328.19.

Kerr, A. C., Aspden, J. A., Tarney, J., & Pilatasig, L. F. (2002). The nature and provenance of accreted oceanic terranes in western Ecuador: geochemical and tectonic constraints. Journal of the Geological Society of London, 159(5), 577–594. https://doi.org/10.1144/0016-764901-151

Lavenu, A., Noblet, C., Bonhomme, M. G., Egüez, A., Dugas, F., & Vivier, G. (1992). New K-Ar age dates of Neogene and Quaternary volcanic rocks from the Ecuadorian Andes: Implications for the relationship between sedimentation, volcanism, and tectonics. Journal of South American Earth Sciences, 5(3–4), 309–320. https://doi.org/10.1016/0895-9811(92)90028-W

Lavenu, A., Noblet, C., & Winter, T. (1995). Neogene ongoing tectonics in the Southern Ecuadorian Andes: analysis of the evolution of the stress field. Journal of Structural Geology, 17(1), 47–58. https://doi.org/10.1016/0191-8141(94)E0027-V

Lavenu, A., Winter, T., & Dávila, F. (1995). A Pliocene-Quaternary compressional basin in the Interandean Depression, Central Ecuador. Geophysical Journal International, 121(1), 279–300. https://doi.org/10.1111/j.1365-246X.1995.tb03527.x

Luzieux, L., Heller, F., Spikings, R. A., Vallejo, C., & Winkler, W. (2006). Origin and Cretaceous tectonic history of the coastal Ecuadorian forearc between 1 ° N and 3 ° S : Paleomagnetic , radiometric and fossil evidence. 249(3–4), 400–414. https://doi.org/10.1016/j.epsl.2006.07.008

Marocco, R., Lavenu, A., & Baudino, R. (1995). Intennontane Late Paleogene-Neogene Basins of the Andes of Ecuador and Peru: Sedimentologic and Tectonic Characteristics. Petroleum Basins of South America, 62, 597–613.

Martin-Gombojav, N., & Winkler, W. (2008). Recycling of proterozoic crust in the andean amazon foreland of Ecuador: Implications for orogenic development of the Northern Andes. Terra Nova, 20(1), 22–31. https://doi.org/10.1111/j.1365-3121.2007.00782.x

Mello, M. R., Koutsoukos, E. A. M., & Erazo, W. Z. (1995). The Napo Formation, Oriente Basin, Ecuador: Hydrocarbon Source Potential and Paleoenvironmental Assessment. 1990, 167–181. https://doi.org/10.1007/978-3-642-78911-3_10

Moore D., and Reynolds R., (1997), X-Ray Diffraction and the Identification and Analysis of Clay Minerals: Oxford University Press, 2nd edition, 332 p., New York.

Noble, S. R., Aspden, J. A., & Jamielita, R. (1997). Northern Andean crustal evolution: New U-Pb geochronological constraints from Ecuador. Bulletin of the Geological Society of America, 109(7), 789–798. https://doi.org/10.1130/0016-7606(1997)109<0789:NACENU>2.3.CO;2

Pardo-Trujillo, A., Cardona, A., Giraldo, A. S., León, S., Vallejo, D. F., Trejos-Tamayo, R., Plata, A., Ceballos, J., Echeverri, S., Barbosa-Espitia, A., Slattery, J., Salazar-Ríos, A., Botello, G. E., Celis, S. A., Osorio-Granada, E., & Giraldo-Villegas, C. A. (2020). Sedimentary record of the Cretaceous–Paleocene arc–continent collision in the northwestern Colombian Andes: Insights from stratigraphic and provenance constraints. Sedimentary Geology, 401. https://doi.org/10.1016/j.sedgeo.2020.105627

Reinoso, M. (2021). Stratigraphic and tectonic characterization of the Peñas Coloradas Formation, and its relation with the deposits of the Chota formation in the Chota Basin of northern Ecuador. Yachay Tech.

Romeuf, N., Aguirre le Bert, L., Soler, P., Féraud, G., Jaillard, E., & Ruffet, G. (1995). Middle Jurassic volcanism in the Northern and Central Andes. Revista Geológica de Chile: An International Journal on Andean Geology, 22(2), 245–259. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_7/b_fdi_51-52/010019756.pdf

Ruiz, G. M. H. (2002). Exhumation of the northern Sub-Andean Zone of Ecuador and its source regions: a combined thermochronological and heavy mineral approach (Issue 14905) [Eidgenössische Technische Hochschule Zürich]. http://e-collection.ethbib.ethz.ch/eserv/eth:26221/eth-26221-01.pdf%5Cnhttp://e-collection.library.ethz.ch/view/eth:26221?q=Exhumation of the northern

Ruiz, G. M. H., Seward, D., & Winkler, W. (2004). Detrital thermochronology - A new perspective on hinterland tectonics, an example from the Andean Amazon Basin, Ecuador. Basin Research, 16(3), 413–430. https://doi.org/10.1111/j.1365-2117.2004.00239.x

Shanmugam, G., Poffenberger, M., & Toro Álava, J. (2000). Tide-dominated estuarine facies in the Hollin and Napo (“T” and ’U’) formations (Cretaceous), Sacha field, Oriente basin, Ecuador. American Association of Petrole Geologist. AAPG Bulletin., 84(5), 652–682. https://doi.org/10.1306/c9ebce7d-1735-11d7-8645000102c1865d

Singer, A. (1984). The paleoclimatic interpretation of clay minerals in sediments - a review. Earth Science Reviews, 21(4), 251–293. https://doi.org/10.1016/0012-8252(84)90055-2

Spikings, R. A., Winkler, W., Hughes, R. A., & Handler, R. (2005). Thermochronology of allochthonous terranes in Ecuador: Unravelling the accretionary and post-accretionary history of the Northern Andes. Tectonophysics, 399(1–4), 195–220. https://doi.org/10.1016/j.tecto.2004.12.023

Spikings, R. A., Winkler, W., Seward, D., & Handler, R. (2001). Along-strike variations in the thermal and tectonic response of the continental Ecuadorian Andes to the collision with heterogeneous oceanic crust. 186(1), 57–73. https://doi.org/10.1016/s0012-821x(01)00225-4

Steinmann, M., Hungerbuhler, D., Seward, D., Winkler, W., (1999). Neogene tectonic evolution and exhumation of the southern Ecuadorian Andes: a combined stratigraphy and fission-track approach: Tectonophysics 307, 255–279.

Streit, R. L., Burbank, D. W., Strecker, M. R., Alonso, R. N., Cottle, J. M., & Kylander-Clark, A. R. C. (2015). Controls on intermontane basin filling, isolation and incision on the margin of the Puna Plateau, NW Argentina (~23°S). Basin Research, 29, 131–155. https://doi.org/10.1111/bre.12141

Tao H., Hao L., Li S., Wu T., Qin Z., and Qiu J., (2021), Geochemistry and Petrography of the Sediments From the Marginal Areas of Qinghai Lake, Northern Tibet Plateau, China: Implications for Weathering and Provenance: Front. Earth Sci., 15 September 2021, Sec. Quaternary Science, Geomorphology and Paleoenvironment, Volume 9 – 2021, doi.org/10.3389/feart.2021.725553

Tibaldi, A., & Ferrari, L. (1992). Latest Pleistocene-Holocene tectonics of the Ecuadorian Andes.

Tectonophysics, 205(1–3), 109–125. https://doi.org/10.1016/00401951(92)90421-2

Toro. (2007). ENREGISTREMENT DES SURRECTIONS LIEES AUX ACCRETIONS DE TERRAINS OCEANIQUES : LES SEDIMENTS CRETACE-PALEOGENES DES ANDES D ' EQUATEUR Jorge Toro Alava To cite this version : HAL Id : tel-00174095.

Toro Álava, J., & Jaillard, E. (2005). Provenance of the Upper Cretaceous to upper Eocene clastic sediments of the Western Cordillera of Ecuador: Geodynamic implications. Tectonophysics, 399(1-4 SPEC. ISS.), 279–292. https://doi.org/10.1016/j.tecto.2004.12.026

Tschopp, H. J. (1953). Oil Explorations in the Oriente of Ecuador, 1938-1950. American Association of Petrole Geologist. AAPG Bulletin., 37(10), 2303–2347. https://doi.org/10.1306/5ceadd94-16bb-11d7-8645000102c1865d

Tucker M.E., (2003), Sedimentary Rocks in the Field. The geological field guide series: John Wiley and Sons eds., 234 p.Chichester.

Vallejo, C. (2007). Evolution of the Western Cordillera in the Andes of Ecuador (Late Cretaceous-Paleogene) (Issue 17023) [Eidgenössische Technische Hochschule Zürich]. https://doi.org/https://doi.org/10.3929/ethz-a-005416411

Vallejo, C., Hochuli, P. A., Winkler, W., & Von Salis, K. (2002). Palynological and sequence stratigraphic analysis of the Napo Group in the Pungarayacu 30 well, Sub-Andean Zone, Ecuador. Cretaceous Research, 23(6), 845–859. https://doi.org/10.1006/cres.2002.1028

Vallejo, C., Spikings, R. A., Horton, B. K., Luzieux, L., Romero, C., Winkler, W., & Thomsen, T. B. (2019). Late cretaceous to miocene stratigraphy and provenance of the coastal forearc and Western Cordillera of Ecuador: Evidence for accretion of a single oceanic plateau fragment. In Andean Tectonics. Elsevier Inc. https://doi.org/10.1016/b978-0-12-816009-1.00010-1

Vallejo, C., Spikings, R. A., Luzieux, L., Winkler, W., & Chew, D. (2006). The early interaction between the Caribbean Plateau and the NW South American Plate. Terra Nova, 18(4), 264–269. https://doi.org/10.1111/j.1365-3121.2006.00688.x

Vallejo, C., Winkler, W., Spikings, R. A., Luzieux, L., Heller, F., & Bussy, F. (2009). Mode and timing of terrane accretion in the forearc of the Andes in Ecuador. Memoir of the Geological Society of America, 204(09), 197–216. https://doi.org/10.1130/2009.1204(09)

Van Wagoner J.C., Mitchum R.M., Campion K.M., and Rahmanian V.D., (1990), Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: American Association of Petroleum Geologists, Methods in Exploration Series No. 7, 55 p., Tulsa.

Villagómez, D. (2003). Evolución geológica plio-cuaternaria del valle interandino central en Ecuador (zona de Quito-Guayllabamba-San Antonio) [Escuela Politécnica Nacional]. https://doi.org/10.13140/RG.2.2.18366.43843

Villagómez D., (2003), Evolución geológica Plio-Cuaternaria del Valle Interandino central en Ecuador (zona de Quito-Guayllabamba-San Antonio): Escuela Politécnica Nacional, Tesis de grado previa la obtención del título de Ingeniero Geólogo, Facultad de Geología, Minas y Petróleos, pp. 133 + anexos, Quito.

Villares, F., Montes, C., Reyes, P. S., & Villares, F. (2020). The Peltetec ophiolitic belt (Ecuador): a window to the tectonic evolution of the Triassic margin of western Gondwana. International Geology Review, 00(00), 1–25. https://doi.org/10.1080/00206814.2020.1830313

Winkler, W., Villagómez, D., Spikings, R. A., Abegglen, P., Tobler, S., & Egüez, A. (2005). The Chota basin and its significance for the inception and tectonic setting of the inter-Andean depression in Ecuador. Journal of South American Earth Sciences, 19(1 SPEC. ISS.), 5–19. https://doi.org/10.1016/j.jsames.2004.06.006

Winter, T., & Lavenu, A. (1989). Tectonique active en Équateur : ébauche d ' une nouvelle interprétation géodynamique. Bulletin de l'Institut Français d'Études Andines, 18(1), 95–115. https://www.persee.fr/docAsPDF/bifea_0303-7495_1989_num_18_1_988.pdf

ANNEXES

Annex 01

SPECIMEN IDENTIFICATION

IGNEOUS ROCKS

GENERAL INFORMATION	
ROCK SAMPLE CODE:	MS_SM2_09
THIN SECTION	No
LOCATION:	Yellow Dike at West Chota Formation
COORDINATES:	-
ROCK INFORMATION	
COLLECTOR	Mario And Santiago
COLLECTED DATE	8-Jan-23
DONATED ROCK BY	Mario
DESCRIPTION	
ROCK NAME:	MS_SM2_09
CLASIFICATION	Extrussive or Volcanic Rocks
SUBCLASIFICATION	Terminologoy of volcanic rocks with M<90%, QAP
COLOR	Dark Greenish Yellow
TEXTURAL FEATURES	
CRYSTALINITY	Perhyaline, dominantly glassy
ROCK TEXTURE	Cryptocristallyne
GRAIN SIZE	Aphanitic
GRAIN SIZE VARIATION	Porphyritic (bimodal)
GRAIN SHAPE	Subhedral
STRUCTURES	Microfractures
ALTERATION or WHEATHERING	
TYPE	Whether Rock
STYLE	Subaerial Environment
INTENSITY	Medium
MINERALS	Plagioclase to clays

IGNEOUS ROCKS

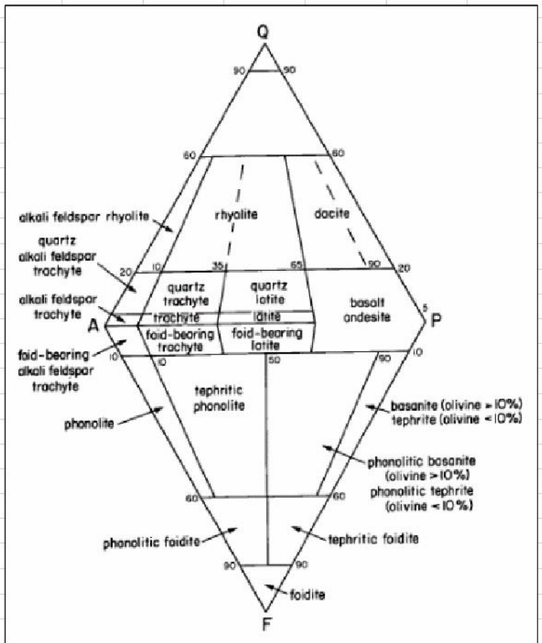

Fig. 1.29 Terminology of volcanic rocks with M < 90% and using the QAPF double triangle (IUGS recommendations from Le Maitre, 1989).

COMPOSITION

PRIMARY MINERALOGY		SECONDARY MINERALOGY	
MINENRAL	%	MINENRAL	%
Plagioclase	13	Vitric Glass	81
Quartz	3	Black Minerals	3

MATRIX	No
VEINS	No
Final Name	QAP = 18.75/0/81.25 Dark Greenish Yellow, cryptocristallyne, aphanitic , porphyritic Andesite containing wheater plagioclase

AVAILABLE PHOTOGRAPHS

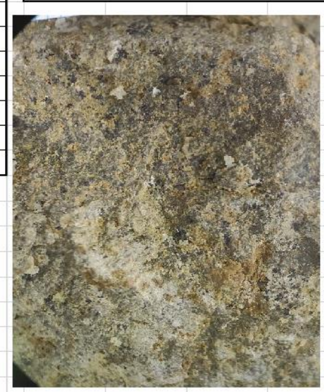

Figure 44.-[Petrographic description of igneous rock]

Anexx 02

Table 6.-[KEY Facies Codes]

Facies Code	***Name***
CaTbL	Reworked Sediments
M-OLSH	Middle to Outer shelf
MISh	Middle to Internal Shelf
Edge Platform	Efge Platform
Pro delta	Pro Delta
delta front	Delta front
Delta plain	Delta Plain
AMS	Abandoned Mudstones
FLdPl	Flood Plain
FlPl	Fluvial Plane
DMB	Distributary Mount Bar
FlCh	Fluvial Chanel
dFlCh	distal Fluvial Chanel
dAFL	distal Alluvial Fan
DF	Debris Flow
dPDC	distal Pyroclastic Density Current
PF	Pyroclastic Flow

Anexx 03

SEDIMENTARY DESCRIPTION

GENERAL INFORMATION	
ROCK SAMPLE CODE	JM_01
LOCATION:	Western Chota Formation
COORDINATES:	-
ROCK INFORMATION	
COLLECTORS	Humanante Mario, Toro Jorge.
COLLECTED DATE	11-Jan-23
DONATED ROCK BY	Mario
DESCRIPTION	
ROCK NAME:	Limestone
CLASIFICATION	Carbonate Rock
SUBCLASIFICATION	Dunham 1962 Carbonate Classification
COLOR	Cream White Ligth Yelowish
TEXTURE	
GRAIN SIZE	Max Intraclast-7500 micras
GRAIN ROUNDNESS	Sub Angular
SORTING	Poorly Sorted
SEDIMMENTARY STRUCTURES	Thin Lamination

OVERVIEW

COMPOSITION

MINERAL COMPONETS	
MINERAL	**%**
Gray Opal (SiO2)	2.5
Quartz	0.5
Pagioclase	4.75
	7.75

LITHIC FRAGMENTS		
SED / IGN / MET	**LITHIC**	**%**
Igneus	Volcanic	1.5
		1.5

MATRIX	Micrite
CEMENT	CaCO3
CONSOLIDATION	Well Consolidated

EYE NOSE FOSSILS	
FOSSIL	**%**
Gastropods	90
Fish tooth	0.5
Fish Skeleton	0.25
	90.75

EXTRA COMMENTS	It has opal veins. Quartz in fractures that recristalyzed and form apal. It is possible to identify to diferent facies, one facies of "grainstone" and another facies of "packstone".
Final Name:	Cream White Ligth Yelowish Grainstone and the another facies Cream White Ligth Yelowish Packstone.

AVAILABLE PHOTOGRAPHS

Figure 45.-[Sedimentary petrographic of limestones]

Annex 04

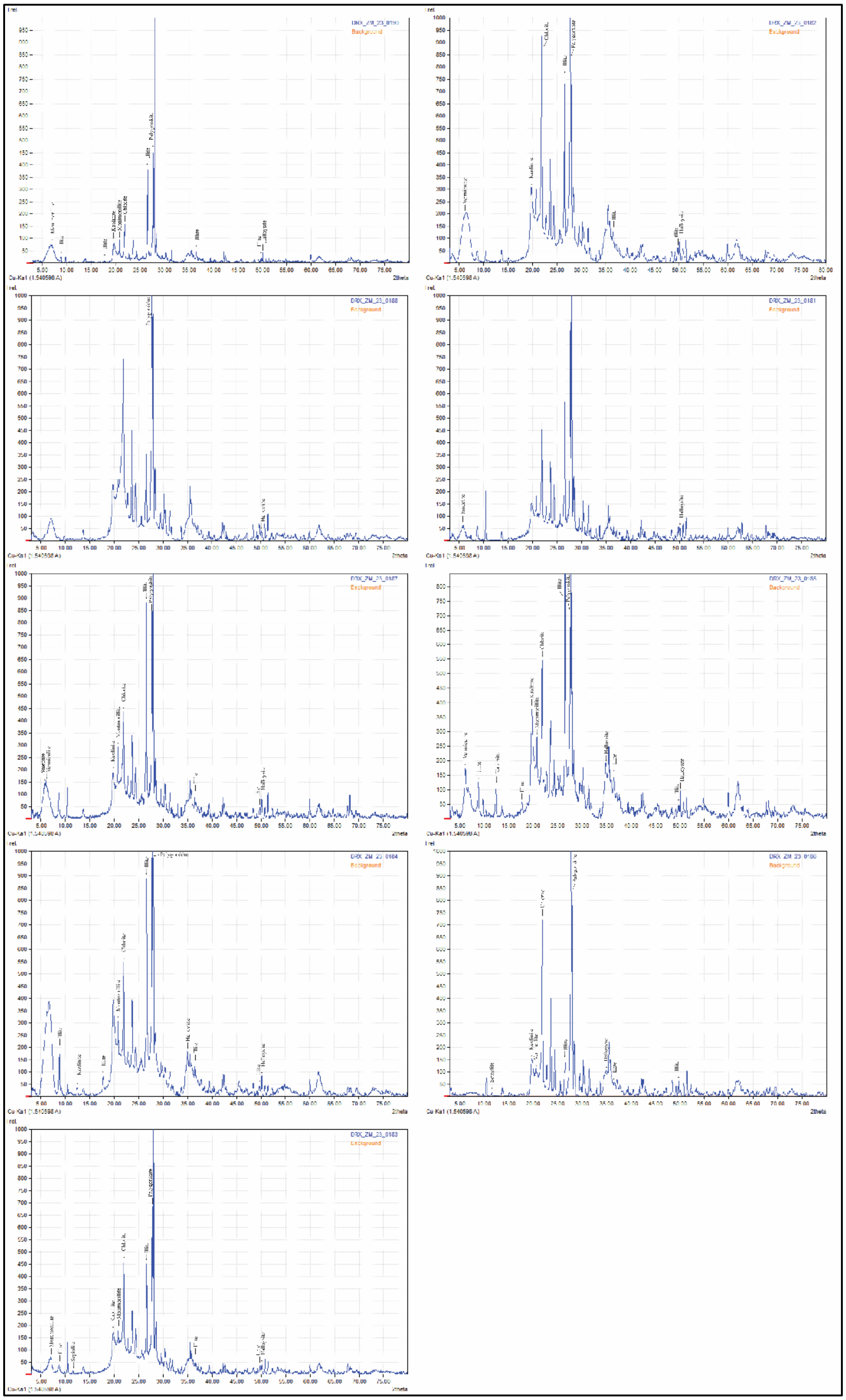

Figure 46.-[XRD pattern generation of the Lower Chota Member.]

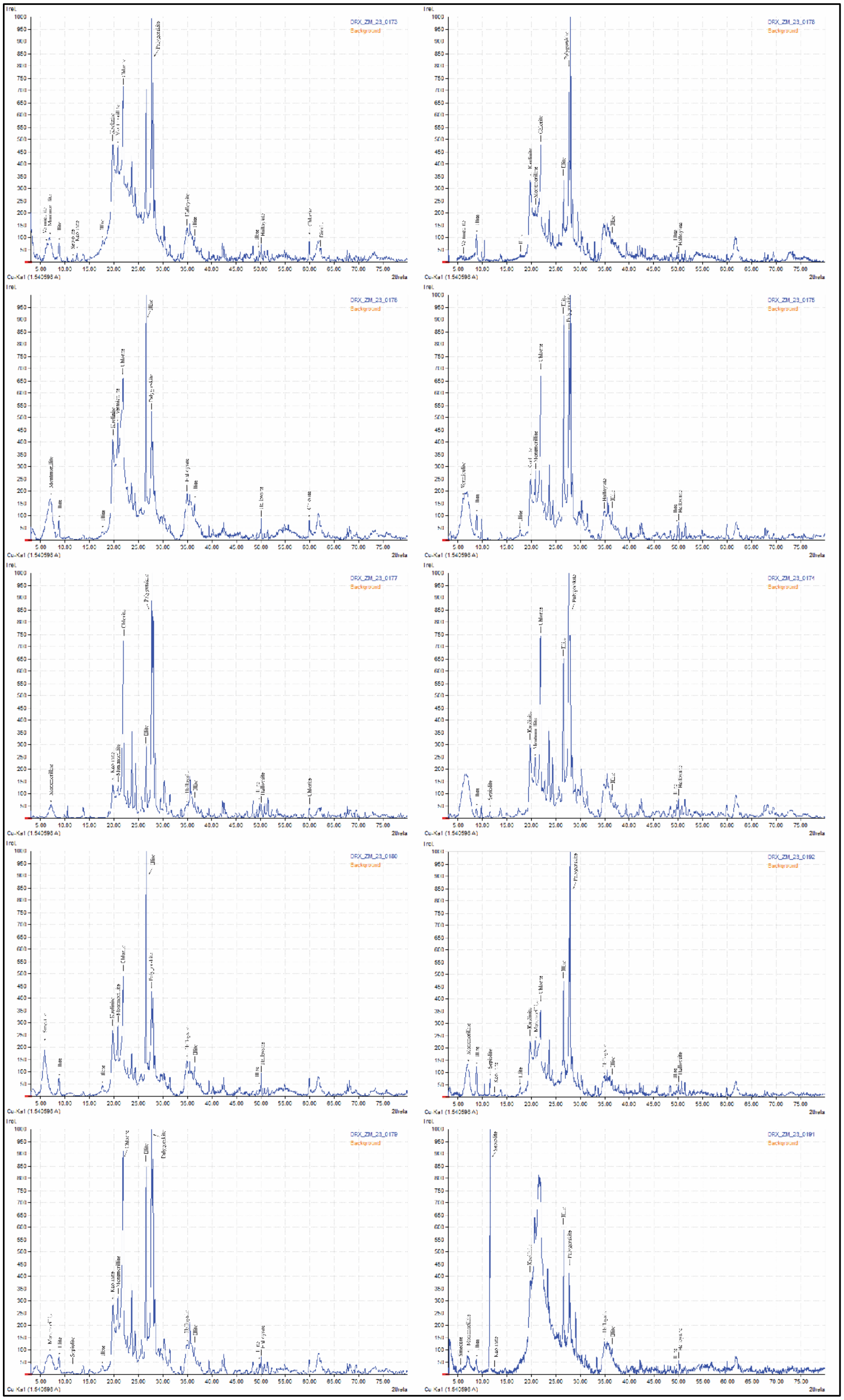

Figure 47.-[XRD pattern generation of the Middle Chota Member.]