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The Maya Are a People of Movement: Reconstructing Shifts in Maya Mobility From Oxygen Isotopes Across Three Millenia at Santa Rita Corozal (Chactemal), Northern Belize

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ABSTRACT

Objectives: Decades of archaeological and bioarchaeological research have demonstrated that ancient Maya cities underwent dynamic changes over time, including shifts in sociopolitical organization as well as their cultural and economic ties to other areas of Mesoamerica. Such transformations are often associated with the movement of people across and beyond the Maya world, but the relationship between temporary and permanent migrations and sociopolitical change is complex and differs over time and between contexts. At Santa Rita Corozal (Chactemal), archaeological evidence indicates that early phases were marked by ties to central Belize and the Petén, while later phases show ties to the Northern Lowlands of the Yucatán. Ethnohistoric records similarly document movements of people between these regions in relation to sociopolitical change prior to the Spanish Invasion and during the Spanish colonial era.

Materials and Methods: Here we reconstruct patterns of mobility at Santa Rita Corozal (SRC) using stable oxygen isotope data from the teeth and bones of 96 Maya Ancestors who span three millennia of continuous settlement from the Middle Preclassic (BCE 800–300) to the Late Postclassic (CE 1350–1532).

Results: Our data reveal non-locals in the Preclassic have δ18O values below the range for SRC, indicating they may have come from highland areas. Conversely, non-locals in the Postclassic have δ18O values above the local range, suggesting that they may have come from low-elevation areas.

Discussion: These movements shed new light on the settlement and demographic history of SRC and help to inform the complex cultural, political, and economic ties evident in the archaeological and ethnohistoric records.

Summary

- Stable oxygen isotope data are presented for Santa Rita Corozal, northern Belize.
- Conservatively, 8 Ancestors (9%) were identified as being nonlocal to Santa Rita Corozal.
- 25% were nonlocal during the Middle Preclassic and 8% during the Late Postclassic.
- $\delta^{18}O$ values from non-local Ancestors from the Preclassic were distinct from those of non-local Ancestors from the Postclassic, indicating movement from different places over time.
- Isotopic data indicate that migration was crucial to the early settlement of Santa Rita Corozal, but less so during the Terminal and Postclassic periods, despite the population apex of the Postclassic.

1 | Introduction

Our knowledge of ancient Maya population movements is informed by various lines of inquiry. This research combines indigenous knowledge with archaeological, oxygen isotope, and ethnohistoric data to amplify current understandings of population movements at the archaeological site of Santa Rita Corozal (Chactemal) in northern Belize. Maya people in what is now known as the Yucatán Peninsula hold deep memories of how their communities have lived in relation to their homelands over time, including the dynamic ways that their peoples have continuously moved across the landscape and interacted across the expanses of the Maya world, past and present. In north coastal Belize where this study takes place, many Yucatec Maya people who live there are descendants of those who moved south across the Rio Hondo following the Caste War of Yucatán in the late 19th century (Dutt 2019; Farriss 1984; Harrison-Buck et al. 2019; Jones 2000; Mongey 2021), while still other Maya peoples in the area moved north and east into Belize following wars and political unrest in what is now El Salvador and Guatemala (Howard 2009; Palacio 1987). The link between sociopolitical change and people's movement therefore lives in the knowledge, memories, and everyday experiences of Maya people in Northern Belize today. While the circumstances of Maya peoples' mobility have changed over the millennia, these movements between the Maya Highlands, Maya Mountains, and the Northern and Southern Maya Lowlands are both ancient and ongoing (Figure 1; Arnauld et al. 2021; Beekman 2019; Farriss 1984; Restall 1997). For the communities we work with, these movements are deeply rooted in what it means to be Maya and are part of how Maya communities have persisted as peoples over time despite periods of profound sociopolitical transformation. In the words of Don Roy Rodriguez, a Yucatec

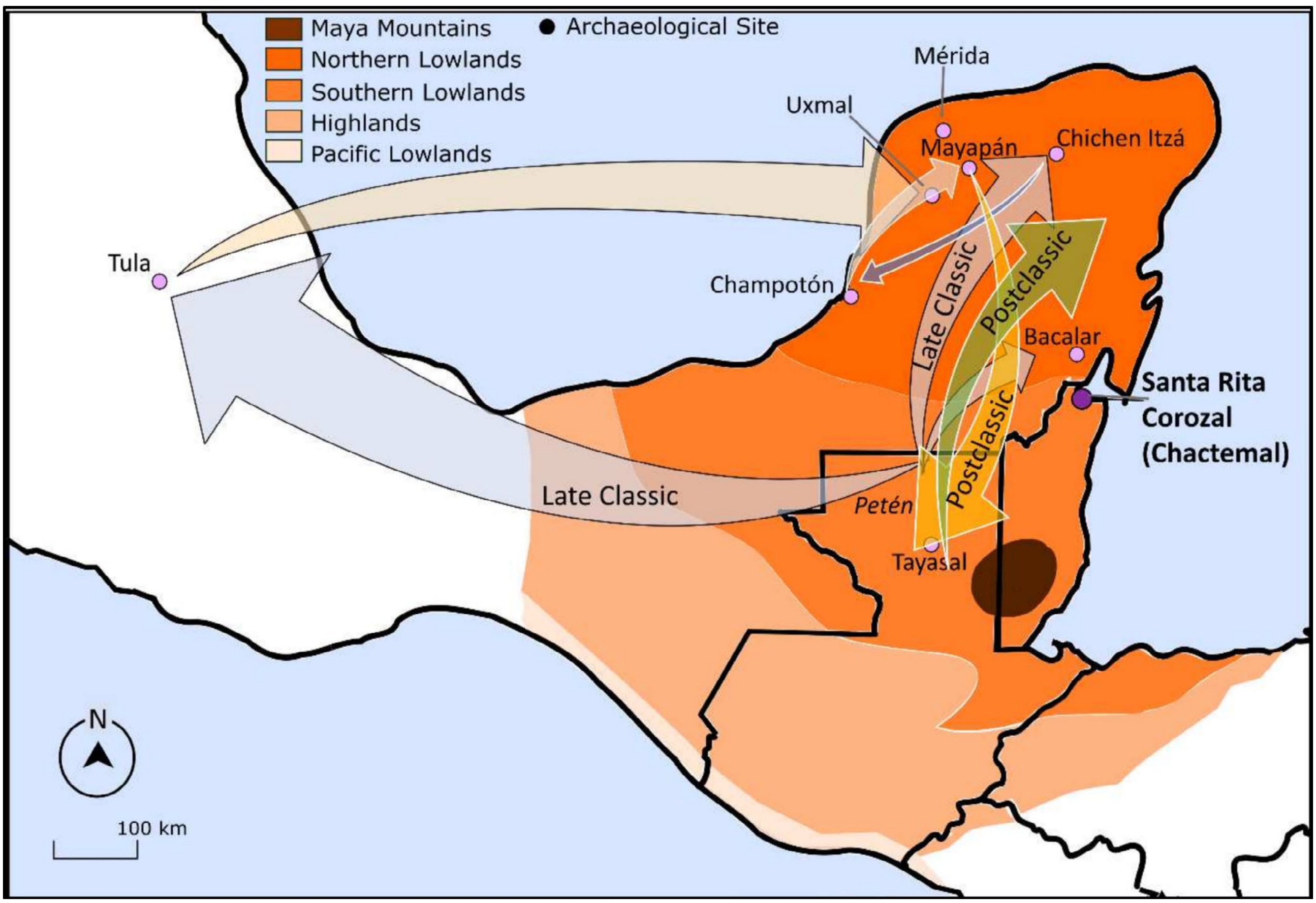

FIGURE 1 | Migration and return migration events during that Late Classic and Postclassic, as described in the Chalam Balam books of Chumayel and Tizimin.
Source: Map adapted from Locker et al. (2023).

Maya man and co-author of this study, "the Maya are a people of Movement."

In addition to the collective memories of contemporary Maya communities, Yucatec Maya people have chronicled their own movements and sociopolitical networks for millennia in books that predate the European invasion. For example, the books of *Chilam Balam* (each named for the Yucatec Maya village where they were kept) provide accounts of Maya mobility in the past. In the *Book of Chilam Balam of Tizimin* and the *Book of Chilam Balam of Chumayel*, Maya writers speak of multiple movement events starting around CE 692 from the Petén area of northern Guatemala and the Mexican Gulf lowlands to the northern Yucatán Peninsula (see Figure 1, light blue arrows; Edmonson 1986, 37; Farriss 1984; Harrison-Buck 2014; Rice 2024). In the Postclassic (CE 900–1532), they refer to a series of return migration events—one from the Yucatán Peninsula back to the Petén area (gold arrow) and a second from the Petén back to the Northern Lowlands of the Yucatán Peninsula (green arrow; Boot 2019; Edmonson 1982, 1986; Freiwald et al. 2020; Harrison-Buck 2014; Jones 1998; Roys 2008).

The *Book of Chilam Balam of Chumayel* details two distinct groups of Mayas who immigrated to the Yucatán Peninsula during the Classic to Postclassic transition (CE 900)—the Itzá of Chichén (and the Petén) resided in the eastern half of the peninsula, while the Xiu, a "Mexicanized" and more distant group, resided in the western part of the peninsula (Edmonson 1986, 2). Beyond the living knowledge and textual records of Maya movements, both linguistic and archaeological evidence also demonstrate the links between movement and sociopolitical organization. For example, the Itzá refer to the western Yucatecans as *Tutul Xiu*, Nahuatl for "Toltec grasses," and linguistic evidence suggests both Nahuatl and Spanish spread through the Yucatán from the west to the east following the sociopolitical and economic networks present between these regions (Edmonson 1986, 3). What is more, linguistic analysis indicates strong ties between the Yucatán, the Petén, and Belize, likely related to the sustained movements and interactions between the Itzá, Kowoj, Kejaches, and Mopan Maya (Jones 1998, 3–28). All four of these groups claim ancestral ties to the Petén, while linguistic evidence also ties them to the Northern Lowlands (Jones 1998, 2000). Evidence of connections among peoples across Mesoamerica is also found in the material culture remains. These point not only to widespread trade networks, but also changing affiliations over time (see for example Feinman et al. 2022). Hieroglyphic records likewise show interconnectedness among elites across various sites and regions (Martin 2020; Munson and Macri 2009). Archaeological evidence suggests that the transition between the Classic (AD 250–900) to the Postclassic (AD 900–1532) was a period of profound sociopolitical dynamism and large-scale population movements in the Southern Lowlands (Figure 2). Over several hundred years, many of the Classic period monumental urban centers such as Tikal, Caracol, Calakmul, Coba, Copan, Palenque, and La Milpa were abandoned

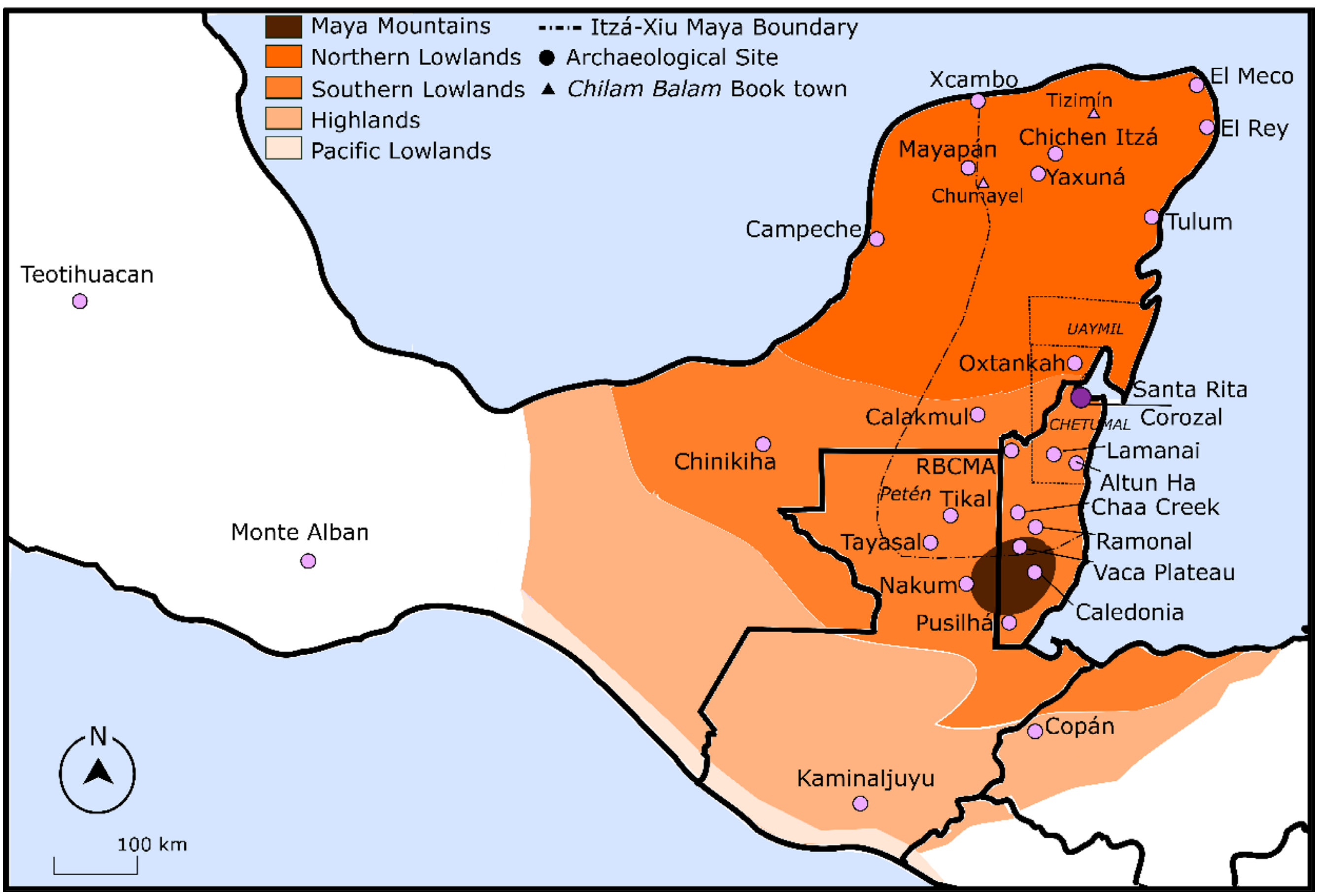

FIGURE 2 | Map of Maya cultural areas, regions, Postclassic provinces, and archaeological sites mentioned in this paper.
Source: Map adapted from Locker et al. (2023) and Chase and Chase (2021).

in the Postclassic period; their inhabitants disappeared—likely moving elsewhere, resettling, and, in some cases, possibly reorganizing themselves in the Northern Lowlands (Aimers 2007; Cowgill 1964; Locker et al. 2023). In essence, non-Isotope datasets show that Mesoamerica shifted back and forth between periods of more cosmopolitan connections and periods of more regional networks over time.

Studies of stable isotopes in the Maya world have also added to our understanding of people's mobility in the past. Meteoric water sources (that is—precipitation, surface waters, and ground waters) vary across a landscape in their composition of oxygen isotopes. Because oxygen isotopes are incorporated into people's teeth and bones from the water they drink, measuring isotope ratios from these tissues provides a signal for where people lived (assumption being that people consume water sources near to their residential locale). In this way, a rich and rapidly growing body of isotopic evidence highlights the dynamism of ancient Maya landscapes and sustained movements of people across spaces and over time (see for example Cucina et al. 2011, 2015; Ebert et al. 2021; Freiwald 2020, 2023; Locker et al. 2023; Negrete et al. 2020; Ortega-Muñoz and Cucina 2021; Price et al. 2008, 2010, 2014, 2018a, 2018b, 2019; Rand 2016; Somerville et al. 2016; Suzuki et al. 2020; Wright 2012; Wright et al. 2010). Much of the focus in isotopic studies of movement enveloping the Classic to Postclassic transition has been centered around sites in the northern Yucatán (Ortega-Muñoz et al. 2019; Price et al. 2012, 2019; Sierra Sosa et al. 2014; Wright 2007) or sites in the Southern Lowlands, with a Postclassic to Colonization focus on inland sites like Lamanai (Donis 2014), Tipu (Trask 2018), or Tayasal (Freiwald et al. 2020). Comparatively less attention has been given to cities intermediate to these areas and how movement in and out of these spaces over time relates to the major sociopolitical transitions across the Maya world. In addition, because Santa Rita Corozal is one of the very few ancient Maya cities in the Southern Lowlands that was continuously occupied before, during, and after the Classic to Postclassic transition, it represents an ideal location to reconstruct a diachronic assessment of people's movement over millennia.

TABLE 1 | Santa Rita Corozal population sizes by major time periods.

Time period	Dates	Population size
Middle preclassic	BCE 900–300	150
Late preclassic	BCE 300 – CE 300	1000
Early classic	CE 300–550	1500
Late classic	CE 550–900	2500
Terminal classic/ early postclassic	CE 900–1200	2000
Late postclassic	CE 1200–1532	7000

1.1 | Santa Rita Corozal (Chactemal)

Santa Rita Corozal is an ancient Maya city located on the western banks of Chetumal Bay in what is now the Corozal District of northern Belize (Figure 1). It is thought to be the location of the capital of the ancient Maya province of Chetumal (Chactemal) (Awe et al. 2020; D. Chase 1986; Chase and Chase 1986, 1988; Iannone et al. 2014). Major formal excavations at Santa Rita Corozal were undertaken by Drs. Diane Z. and Arlen F. Chase as part of the Corozal Postclassic Project

FIGURE 3 | Structure 7, the Political Epicenter of Ancient Santa Rita Corozal.
Source: Photo by R. W. A. Smith.

from 1979 to 1985 (Chase and Chase 1988, 2004). These excavations revealed some of the earliest known Maya burials in Belize in the Middle Preclassic (BCE 800–300, Chase et al. in review), followed by a continuous sequence of settlement across every phase of Maya chronology (see Table 1; D. Chase 1981, 1984; Chase and Chase 1986, 1988, 2005, 2006, 2008, 2020; Chase et al. 2018; Awe et al. 2020; Chase and Chase 2004; Iannone et al. 2014). Major subsequent stabilization work at the site, led by Dr. Jaime Awe, revealed additional Classic and Postclassic interments (Awe et al. 2020). Santa Rita Corozal has a continuous sequence of human settlement in the Maya area, spanning more than three millennia and facilitating an analysis of population dynamics and movement over time (Chase and Chase 1986; D. Chase 1990, 1997; D. Chase et al. 2023, supp. information).

Structure 7 and its corresponding courtyard are among the only surviving edifices of the ancient city's pre- and peri-colonial monumental architecture (Figure 3). In addition to the preservation of these structures as an archaeological reserve by the Institute of Archaeology and the National Institute of Culture and History (NICH) in Belize, these structures are recognized as a temple and a place of deep cultural significance by the contemporary Maya communities living in and around Corozal. Prior to the development of contemporary Corozal Town beginning in the 19th century, the ancient city of Santa Rita Corozal once covered a much wider area than indicated by the surviving structures. During the height of its settlement in the Postclassic, the city spanned what is now the contemporary city of Corozal Town and some of the surrounding Maya villages, extending from San Andres in the southwest to Paraiso in the north and eastward to the edges of Corozal Bay (See Figure 4; D. Chase and A. Chase 1984, 1988, 2004). The villages of San Andres, San Antonio, and Paraiso shown on the map insert of Figure 4 have since been incorporated into Corozal Town as the result of contemporary re-urbanization.

Prior archaeological work at Santa Rita Corozal has involved reconstructing the overall demography of the population, where the size and composition of the population during

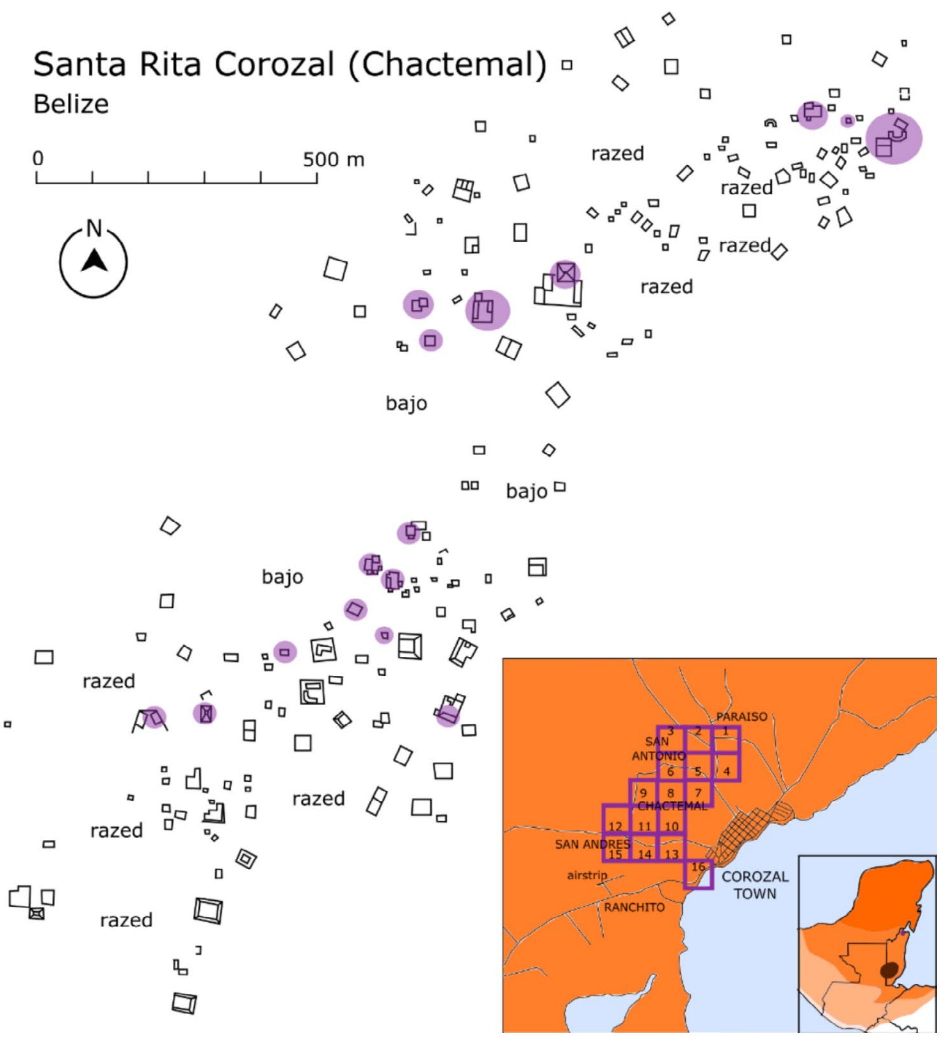

FIGURE 4 | Map of ancient Santa Rita Corozal. The Ancestors who are included in this study were recovered from areas highlighted in circles. The grid on the map insert indicates 500 by 500 m areas of the city, as designated by the Corozal Postclassic Project. The larger map shows the structures from quadrants 1–12 and 14–15.
Source: Image adapted from A. Chase and D. Chase (2020).

each phase of occupation were estimated from the quantities of known interments and structural material dating to each major time period (D. Chase 1990). The earliest Maya settlement at the site appears in the Middle Preclassic as a small village occupied by approximately 150 residents (D. Chase 1990; Chase and Chase 2004; Iannone et al. 2014). Archaeological evidence suggests that early settlement was likely restricted to the Southwest and North Central Sectors of the site (D. Chase 1990; Chase and Chase 1988, 2004; Iannone et al. 2014). By the Late Preclassic (BCE 300—CE 300), Santa Rita Corozal's population grew to approximately 1000 residents (Chase and Chase 2004; Iannone et al. 2014). Evidence for occupation from this period spans the full extent of the site (Chase and Chase 1986, 1988).

Santa Rita Corozal continued to grow in the Early Classic (AD 300–550) to approximately 1500 people (Chase 1990; Chase and Chase 1988, 2005; Iannone et al. 2014). Despite the relatively small population, archaeological evidence indicates clear markers for the development of social hierarchy and the construction of monumental architecture with elaborate tombs (Chase and Chase 2004, 2005). Indeed, it has been suggested that the ruling elite class who emerged during this time represents a centralized and dynastic lineage or divine kingship that spanned generations (Chase 1985; Chase and Chase 2021). Because of its positioning near the confluences of the Rio Hondo, the New River, and the Caribbean coast, Santa Rita Corozal became a significant trade center beginning in the Early Classic, trading cacao, honey, vanilla, annatto, and marine foods with inland sites in northwestern and central Belize, the Petén, and the Yucatán (Awe et al. 2020; Chase 1986; Chase and Chase 1989, 2004, 2005, 2020). Ceramic analyses have indicated that Santa Rita Corozal had ties to both the Southern and Northern Lowlands in the Early Classic, and the site functioned as an independent regional power rather than being directly controlled by polities in other regions (Chase and Chase 2005; Iannone et al. 2014).

By the Late Classic, the site continued to grow to approximately 2500 residents, though archaeological evidence indicates that social hierarchy and distinctions between classes became less pronounced (Chase and Chase 2004; Iannone et al. 2014). Santa Rita Corozal also experienced a slight decline in population during the Terminal Classic/Early Postclassic Period (CE 900–1200) to approximately 2000 residents (Chase 1990; Chase and Chase 2004); however, the city regained greater control over trade routes and access to external markets (Iannone et al. 2014). Contrary to most other Southern Lowland sites, which were depopulated after the Terminal Classic, Santa Rita Corozal's settlement history mirrored other Maya sites in the Northern Lowlands, such as Mayapán, and a select few sites in the Southern Lowlands of northern Belize, such as Lamanai, which continued to flourish into the Late Postclassic and beyond (Andrews 1993; Aimers 2007; Hanna et al. 2016; Milbrath and Peraza Lope 2003; Pendergast 1986).

Santa Rita Corozal reached its fullest population size and political influence during the late facet of the Late Postclassic (1350–1532), due in part to its key positioning on major waterways and accessibility to marine food sources and fresh water (Iannone et al. 2014). Indeed, Santa Rita Corozal is perhaps most well-known for its Late Postclassic occupation, where it regained power over the Corozal Bay and became the capital of the Chetumal Province (Awe et al. 2020; Chase 1986; Chase and Chase 1986, 1988; Iannone et al. 2014). The population more than tripled to over 7000 residents during this time (Chase 1990; Chase and Chase 2004; Iannone et al. 2014). The sociopolitical organization and regional connections at Santa Rita Corozal also appear to have shifted during the Postclassic. Archaeological evidence demonstrates that elite burials shifted from a concentration within the city's epicenter to multiple palace-like residences distributed throughout the site (Chase 1985, 1986, 1992), indicating a rupture of any centralized divine kingship that had typified the earlier Classic Period (Chase and Chase 2021). In addition, ceramic effigy cache figures dating to this period indicate close ties to Mayapán (Chase and Chase 2008), and Mixteca-Puebla styled painted murals found in Mound 1 at the end of the nineteenth century (Gann 1900) indicate close ties to sites in the Northern Lowlands, notably Mayapán and the western Yucatán settled by the "Mexicanized" Xiu Maya peoples (Chase and Chase 1988, 2004, 2008; Iannone et al. 2014).

1.2 | Study Objectives

Taken together, the knowledge of the contemporary Maya community in and surrounding Corozal, combined with ethnohistoric, linguistic, archaeological, and bioarchaeological records, indicates that Santa Rita Corozal has been a place of dynamic population change for almost three millennia. The city underwent multiple transformations in its social structure, political organization, and the shape of its economic networks as it rose to become a regional Maya capital in the Postclassic. Here, we seek to reconstruct patterns of Maya mobility at Santa Rita Corozal in relation to its social, political, and demographic changes over time. Given multiple lines of evidence describing Maya movements and shifting sociopolitical ties in antiquity, we made the following four predictions about Maya mobility at Santa Rita Corozal over time. First, we predicted that migrants to the city during different time periods would come from distinct regions of the Maya world. Second, we predicted an influx of non-local people during the Middle Preclassic when the city was first established. Third, given the dramatic change in sociopolitical organization and the remapping of regional networks during the Postclassic, we predicted that the Classic to Postclassic transition would be an inflection point in the origins and number of migrants to Santa Rita Corozal. Fourth, given the ties to the Northern Lowlands that appear in the archaeological record in the Late Postclassic at Santa Rita Corozal, we predicted that migrants to the site will be drawn from that region. Alternatively, and perhaps simultaneously, given the depopulation of sites across the Southern Lowlands in the Terminal Classic, migrants may also have arrived at Santa Rita Corozal from these spaces during the Postclassic. Based on the books of the Chilam Bilam, it seems likely that both migration scenarios might be occurring, with migrants arriving at Santa Rita Corozal in the Postclassic from multiple regions, including the Northern and Southern Lowlands. To address these questions, we measured stable oxygen isotopes of the dental enamel and bones from 96 Maya Ancestors[1] spanning every phase of Maya chronology that were recovered during the archaeological excavations of the Corozal Postclassic Project.

2 | Methods

2.1 | Ethics Statement

This project adheres to all existing international legal and ethical standards for bioarchaeological research and works beyond these minimum standards to address additional guidelines as defined by our local community research partnerships in Belize. The Maya Ancestors included in this research resulted from archaeological excavations carried out at Santa Rita Corozal under the Corozal Postclassic Project from 1979 to 1985 by Drs. Diane Z. Chase and Arlen F. Chase (Chase and Chase 2020; ASZ Chase et al. 2018; Chase 1981, 1984, 1985, 1986; Chase and Chase 1988, 2004, 2005). All Ancestral remains are curated at the University of Houston and were transported to the US under the authority of the Belize Department of Anthropology (now Institute of Archaeology, IoA). Approval for the isotopic work presented in this paper was provided to Smith by the archaeological project and by the IoA. In addition to institutional approval from the governing bodies in Belize, we have also co-developed this work with our local Maya research partners in northern Belize. This work received support from members of the board of the Maya-led NGO To'one Masehualoon (Yucatec Mayan meaning "We are Maya") headquartered in Corozal Town, Belize. Their work focuses on raising consciousness about Maya communities in northern Belize, sustaining Maya cultures and lifeways, and Yucatec Mayan language revitalization. In collaboration with To'one Masehualoon, we have conducted over 100 meetings and interviews with Maya people in Corozal and the surrounding Maya villages of Cristo Rey, Libertad, Louisville, Pachakan, Santa Clara, San Pedro, San Victor, Xaibe, and Yo Chen. The goals of this research and its outcomes were co-developed through these local partnerships. Preliminary findings presented in this paper were first delivered to Maya communities through two public forums in June 2023 co-hosted by the Critical Molecular Anthropology Laboratory group at George Mason University (PI Smith), To'one Masehualoon, and the National Institute of Culture and History in Belize. The first forum was delivered in English at the House of Culture in Corozal and the second was delivered in Spanish at the Janal Yucatec Maya Restaurant in Xaibe Village. Maya partners also visited the Critical Molecular Anthropology Lab at George Mason University in May 2024 for laboratory protocol co-development and continued strategic planning related to the research goals. At every stage, we received guidance from our research partners and Maya community members which has been integral to producing the work presented here.

2.2 | Ancestors Included in This Research

We selected 96 Ancestors for this research. These Ancestors span the Middle Preclassic (800 BCE—400 BCE) through the Late Postclassic (1350 CE—1532 CE) periods (Table S1). When available, both dental and skeletal elements were selected from each Ancestor. The Ancestors included in this research come from discrete interments, so some Ancestors have paired bone and teeth tissues ($n = 51$ Ancestors). However, due to preservation and availability, some Ancestors are only represented by bone elements ($n = 16$ Ancestors), while others are only represented by dentition ($n = 29$ Ancestors). Table 2 shows a brief outline of different combinations of elements from individual Ancestors. A full list of skeletal elements, including paired bone and enamel tissues, can be found in Table S1.

TABLE 2 | Breakdown of how ancestors are represented across sampling strategies for this research.

Skeletal sample classes	Number of distinct ancestors	Total number of teeth	Total number of bones
Single tooth	18	18	0
Single bone	12	0	12
Multiple teeth	11	23	0
Multiple bones	4	0	8
Single tooth; multiple bones	16	16	32
Single tooth; single bone	19	19	19
Multiple bones; multiple teeth	8	16	16
Multiple teeth; single bone	8	16	8
Total	96	108	95

Because dental enamel does not remodel over an individual's life, molars and premolars were analyzed to gauge movement during childhood. This is because the first molar (M1) crown finishes mineralizing in early childhood, the second molar (M2) and premolar (PM) crowns finish mineralizing in middle childhood, and the third molar (M3) crown finishes mineralizing in the early teenage years (Ash and Nelson 2003). We preferentially selected M1 ($n = 48$) and M3 ($n = 44$) from Ancestors. If unavailable, we selected M2 ($n = 7$), PM ($n = 5$), or unclassified molars ($n = 4$). Importantly, 26 Ancestors have multiple teeth represented in this dataset.

In contrast, bones do remodel over the life course and were therefore selected as a measure of later-in-life movement. Appendicular long bones (i.e., femora, tibia, humeri, etc.) typically remodel over 30 years (Ubelaker and Buikstra 1994) and were selected to gauge the length of time an individual may have lived in Santa Rita Corozal, if born elsewhere. Axial bones (i.e., clavicle, ribs) and distal appendicular elements (i.e., phalanges) remodel within the past 7 years of life (Ubelaker and Buikstra 1994), and so were selected to gauge whether an Ancestor had moved to Santa Rita Corozal shortly before death. In total, we measured stable oxygen isotopes from bone carbonate ($n = 95$) and enamel carbonate ($n = 108$) from 96 Ancestors. Here, we present the bone carbonate ($n = 46$) and enamel carbonate ($n = 100$) data that passed quality control (QC) from a total of 85 Ancestors (see below for quality assessments). All data, including data that did not pass QC, are available in Table S1.

2.3 | Oxygen Isotopes and Movement

Oxygen isotopes are integrated into the body's tissues via consumption of meteoric water from the local landscape (Dupras and Schwarcz 2001; Grimes and Pellegrini 2013; Lightfoot and O'Connell 2016; Locker et al. 2023; Pederzani and Britton 2019; Slovak and Paytan 2011; Stephan 2000). Since meteoric water varies across landscapes due to differences in elevation, latitude, distance from the source of evaporation, precipitation patterns, seasonality, cooling history of the air, and humidity—movement can be studied by measuring oxygen isotopes in a person's bone and dental enamel. As noted above, enamel represents periods during childhood, while bones can represent periods closer to time of death (axial bones) or an average of the past 30 years of life (appendicular long bones). When comparing the measured $\delta^{18}O$ values of skeletal elements to established ranges for the location of interment, individuals whose teeth and/or bones have $\delta^{18}O$ values that fall outside the established local range will have likely spent specific periods of their lives away from the location of interest (Dupras and Schwarcz 2001; Freiwald 2023; Lightfoot and O'Connell 2016; Locker et al. 2023; Pederzani and Britton 2019).

2.4 | Dental Enamel and Bone Carbonate Sample Preparation

Prior to wet chemistry, tooth surfaces were carefully cleaned with individual sterile brushes to collect phytoliths and microbotanicals for future research before ultrasonic cleaning in 18.2 megohm-cm ultrapure water (D2) for 15 min. Following ultrasonication, tooth surfaces were scrubbed with new individual brushes to remove and preserve any remaining phytoliths for future research. Teeth were rinsed with D2 and left to air dry overnight. Enamel surfaces were lightly abraded using a Dremel rotary tool fitted with a carbide burr. Following abrasion, approximately 10 mg of enamel was drilled from each tooth using a Dremel rotary tool fitted with a clean carbide burr. To help lessen the influence of seasonality in the isotopic composition of drinking water as well as heterogeneous isotope deposition across the enamel surface, we drilled bulk samples in longitudinal lines from just above the cemento-enamel junction to just below the occlusal surface. To prevent cross-contamination between Ancestors, gloves were changed, and drills, bits, and work surfaces were cleaned with DNA Away, D2, and ethanol between preparations.

For preparation of bone samples, small pieces (1–2 mm in size) were removed from the densest portion of the bone with a chisel and ultrasonically cleaned in D2 for 30 min. Sonication was repeated until the water remained clear. Bone samples were left to air dry for 2 days, powdered with a stainless-steel mortar and pestle, and sieved to achieve a granular size $<125\,\mu m$. To ensure cross-contamination between Ancestors did not occur, gloves were changed, the sieve was cleaned with ethanol, and the mortar and pestle and workspace were cleaned with 50% bleach, D2, and ethanol between preparations. The resulting powder for dental drilling and bone grinding was placed in sterile 1.5 mL centrifuge tubes.

Following a modified protocol from Garvie-Lok et al. (2004), resulting powders were further processed in the Bioarchaeology & Stable Isotope Research Lab (BSIRL) at Vanderbilt University. Bone powder samples were soaked in 1 mL of 1%–1.5% sodium hypochlorite (NaOCl) for 48 h. Three rinses were completed with D2. Bone powder samples were then soaked in 0.5 mL of 0.1 M acetic acid for 3.5 h. Samples were centrifuged, triple rinsed with D2, and placed in a dry bath set at 60°C for 2–3 h before they were left to dry at room temperature in a desiccator for 2 days. Enamel powder samples were soaked in 1 mL of 2%–3% NaOCl for 24 h. Three rinses were completed with D2. Enamel powder samples were then soaked in 0.5 mL of 0.1 M acetic acid for 3.5 h. Samples were centrifuged, triple rinsed with D2, and placed in a dry bath set at 60°C for 2–3 h before they were left to dry at room temperature in a desiccator for 2 days.

All powders were sent to the Stable Isotope Laboratory in the Jackson School of Geosciences at the University of Texas at Austin for mass spectrometry. Approximately 3 mg of each powdered sample was loaded into borosilicate glass vials with 15 mg of silver to help trap potential sulfur dioxide liberated during acidification (Kusaka and Nakano 2014). Vials were loaded into a Gasbench II autosampler tray and flushed with helium for 10 min. Powder samples were reacted with 0.2 mL of 103% phosphoric acid for a minimum of 4 h and equilibrated at 50°C. Liberated CO_2 then passed through a GC column held at 30°C and analyzed using a Thermo MAT253 isotope ratio mass spectrometer in continuous flow mode.

All $\delta^{18}O$ values presented here are reported on the Vienna Standard Mean Ocean Water (VSMOW) scale. The measured $\delta^{18}O$ values were calibrated on a three-point curve using NBS-18 (Carbonate; +7.20‰ VSMOW), NBS-19 (Limestone; +28.65‰ VSMOW), and an internal standard (Marble [UTM]; +26.50‰ VSMOW). Precision (standard deviations) for all standards ranged from 0.1‰ to 0.2‰ (see Table S2).

2.5 | Diagenesis

To assess the preservation of bone, a portion of the chemically processed bone powders was analyzed on a Thermo Scientific Nicolet iS 5 Fourier transform infrared (FTIR) spectrometer in attenuated total reflection (ATR) mode in the Department of Chemistry at Vanderbilt University. Approximately 1 mg of processed bone powder was placed on the diamond crystal optic window. Spectra were collected from 4000 to 400 cm^{-1} as the average of 64 scans with a resolution of 8 cm^{-1}. The optic window, plate, and pressure applicator were cleaned with isopropanol between each measurement. Background scans were completed at the beginning of each run, after every 10 unknowns, and at the end of each run to help normalize the data during the analysis stage.

Spectra were analyzed using OMNIC 9 software (Thermo Scientific, version 9.2.86). An Auto Baseline correction was completed to ensure all spectra were read above or at 0.00 absorbance. An ATR Correction was completed in the software to adjust for shifting that occurs in the absorption bands from the diamond prism. Following France et al. (2020), we used three baseline ranges to measure various peaks necessary to calculate the most common ratios used to assess diagenetic alteration and bone preservation (Table S3, Table S4).

France et al. (2020, 13) suggest that *C*/*P* ratios are "the more valuable indicator of preservation status for bone" if the samples have been chemically treated to remove organics and exogenous carbonates. Following this, we use *C*/*P* ratios in conjunction with IR-SF values and extend the threshold for IR-SF values to a range of 2.5–4.5 and follow a *C*/*P* range of 0.05–0.32 (France et al. 2020; Hopkins et al. 2016). Four bone powders did not have enough material after isotopic analysis to measure on the FTIR. Because of the high variability in sample preservation, we have excluded them from this study. Among the original 95 samples processed, the final analysis includes 46 bone samples with viable $\delta^{18}O$ values (see Table S1).

2.6 | Statistical Approach

The oxygen isotope data generated in this study were analyzed in the R statistical environment (R Core Team 2023) using native tools as well as the tidyverse (Wickham et al. 2019), e1071 (Meyer et al. 2023), and dplyr (Wickham et al. 2023) packages. Data were visualized using ggplot2 (Wickham et al. 2024), ggpubr (Kassambara 2023), ggthemes (Arnold et al. 2024), plotly (Sievert et al. 2024), and wacolors (McCartan 2022).

2.6.1 | Defining the Local Range of Oxygen for Santa Rita Corozal

To determine the number and potential source locations of migrants to Santa Rita Corozal, the range of oxygen isotope values local to the area around the site must first be defined (Freiwald 2011; Locker et al. 2023; Pederzani and Britton 2019; Price et al. 2002). Once a local range is established, individuals whose dental or skeletal $\delta^{18}O$ values fall outside the local range may be identified as non-local to the area. In other words, any Ancestor whose $\delta^{18}O$ value falls below or above the local range is non-local.

There are several approaches to establishing a local range. For example, many archaeological studies use precipitation and surface water samples (i.e., drinking water) to establish a local oxygen isotope range (see for example Chenery et al. 2012; Daux et al. 2008; Dotsika 2020; Pellegrini et al. 2016; Pollard et al. 2011; Scherer et al. 2015). However, research shows that $\delta^{18}O$ values of meteoric water in Mesoamerica can change throughout a given year due to hydrologic processes such as drought, evaporation, wet-dry seasonality, recharge, and strong storms (Fan et al. 2022; García-Santos et al. 2022; Lachniet and Patterson 2009; Paíz et al. 2023; Sánchez-Murillo et al. 2020; Wassenaar et al. 2009). Additionally, $\delta^{18}O$ values of human bone and dentition can differ from those of water sources due to the accessibility of those water sources, breathing, different cooking processes, expelling waste, ingestion of water from food sources, seasonality, and sweating (Dupras and Schwarcz 2001; Lightfoot and O'Connell 2016; Locker et al. 2023; Pederzani and Britton 2019; Pellegrini et al. 2016). To circumvent these issues, representative local oxygen isotope ranges can be determined through statistical analyses of the distribution of isotope ratios in dental enamel from a burial population (Lightfoot and O'Connell 2016; Locker et al. 2023; Pellegrini et al. 2016), and this is the approach we use in this study. Specifically, we use Tukey's Interquartile Range (IQR) to define local as ±1.5*IQR beyond Q1 and Q3 of the burial population. This approach is conservative in that it allows for a wider range for local $\delta^{18}O$ values of ancient humans and therefore demands a higher level of distinction in identifying non-local individuals, minimizing the risk of false positives. Using this approach, local ranges for Santa Rita Corozal were determined through measurements of oxygen isotopes from M3 molars. These teeth spanned the Middle Preclassic (BCE 900–300) through the Late Postclassic (CE 1200–1532) and represent 42 Ancestors.

Because natural and anthropogenic processes can alter $\delta^{18}O$ values measured in human dental and skeletal elements over different time periods (Locker et al. 2023; Pederzani and Britton 2019), we included statistical tests to evaluate whether isotopic values covaried with time. If there are no significant differences between $\delta^{18}O$ values and time, then it is feasible to define a single local range for all isotopic data to define non-local individuals. If, however, $\delta^{18}O$ values differ significantly between time periods, it would be necessary to define multiple local ranges to define non-local values within each temporal subset. Therefore, prior to identifying non-local individuals, we divided $\delta^{18}O$ values from all M3 enamel samples by major time periods—Middle Preclassic, Late Preclassic, Early Classic, Late Classic, Terminal Classic, and Late Postclassic. We then checked for statistical differences between time periods using Kruskal-Wallis tests, one-way ANOVA, and a Tukey's test.

2.6.2 | Comparing Bone Carbonate to Enamel Carbonate Samples

Prior studies have shown that there are different fractionation factors impacting the carbonate component of bone and enamel skeletal elements in mammals (Passey et al. 2005; Warinner and Tuross 2009; Webb et al. 2014). This results in an offset between $\delta^{18}O$ values. To compensate for this offset, we adjusted the $\delta^{18}O$ values of our measured bone samples by +1.4‰, following the study on archaeological human remains by Webb et al. (2014). This adjustment enables us to compare bone carbonates with dental enamel carbonates directly.

2.6.3 | Comparing $\delta^{18}O$ Values Generated in This Study With Prior Data From Other Maya Sites

Multiple previous studies of migratory isotopes have been conducted across Maya sites (Freiwald 2020; Howie et al. 2010; Locker et al., this study 2023; Negrete et al. 2020; Olsen et al. 2014; Ortega-Muñoz et al. 2019, 2021; Price et al. 2002, 2012, 2014, 2018a, 2018b; Rand 2016, 2020; Sharpe et al. 2022; Sierra Sosa et al. 2014; Somerville et al. 2016; Suzuki et al. 2018, 2020; White et al. 1998, 2001, 2002, 2004a, 2004b, 2007; Wright 2012; Wright et al. 2010). These studies defined their local $\delta^{18}O$ ranges using multiple statistical approaches. These approaches vary in identifying non-local individuals from taking the mean of the dataset ±1‰ (Howie et al. 2010; White et al. 2001, 2007; Wright et al. 2010), to taking the mean of the dataset ±1 standard deviation (Rand 2016), to taking the

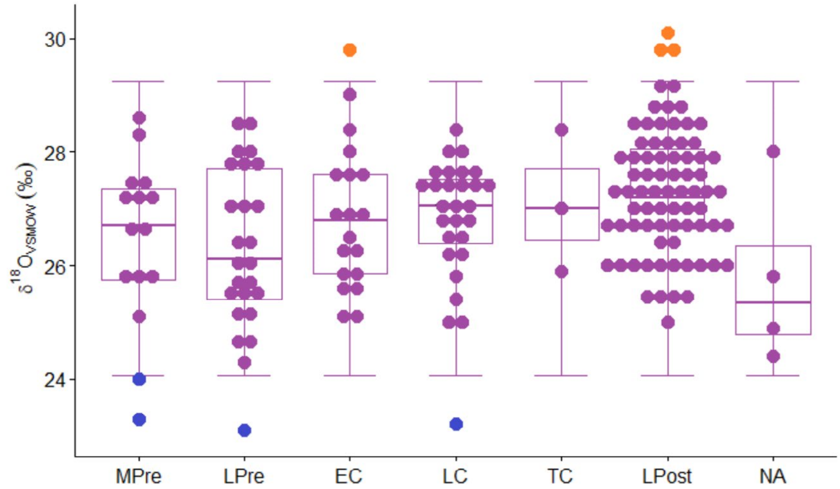

FIGURE 5 | Boxplot of $\delta^{18}O$ values of bone and enamel samples through time. Whiskers reflect the local range for oxygen isotopes at Santa Rita Corozal. Local is defined as ±1.5*IQR beyond Q1 and Q3 of M3 enamel samples (Lightfoot and O'Connell 2016; Locker et al. 2023). MPre = Middle Preclassic, LPre = Late Preclassic, EC = Early Classic, LC = Late Classic, TC = Terminal Classic, LPost = Late Postclassic, NA = unknown context. Purple represents the local range for Santa Rita Corozal. Orange dots represent bone and/or enamel of ancestors whose $\delta^{18}O$ values are higher than the local range for Santa Rita Corozal. Blue dots represent bone and/or enamel of ancestors whose $\delta^{18}O$ values are lower than the local range for Santa Rita Corozal.

TABLE 3 | Ancestors included in this study. Results show averaged $\delta^{18}O$ values by time of dental enamel and bone powder samples from Ancestors recovered from archaeological excavations during the Corozal Postclassic Project. Chronology was determined by ceramics recovered from graves.

Time period	No. of ancestors	Average $\delta^{18}O_{VSMOW}$‰ total population	Average $\delta^{18}O_{VSMOW}$‰ excluding non-locals	No. ancestors identified as non-local	% Non-local
Middle preclassic	8	+26.5‰	+26.9‰	2	25%
Late preclassic	9	+26.4‰	+26.6‰	1	11%
Early classic	13	+27.0‰	+26.8‰	1	8%
Late classic	12	+26.9‰	+27.0‰	1	8%
Terminal classic	2	+27.1‰	+27.1‰	0	0%
Postclassic	38	+27.2‰	+27.1‰	3	8%
N/A	3	+26.1‰	+26.1‰	0	0%
Total	85	+26.7‰	+26.8‰	8	9%

mean of the dataset ± 2 standard deviations (Freiwald 2020; Price et al. 2018a, 2018b; Rand et al. 2020; Suzuki et al. 2018, 2020), to ±1.5*IQR beyond Q1 and Q3 (Locker et al. 2023, this study; Negrete et al. 2020; Ortega-Munoz et al. 2019, 2021; Price et al. 2012). To adjust for these differences and make data from prior studies comparable to the data generated in this study, we have re-calculated $\delta^{18}O$ ranges for each of the sites included on this map using ±1.5*IQR beyond Q1 and Q3 of the original datasets. Note, this recalculation using IQR statistics changes the original local ranges for many of these sites, and thus, lowers the number of non-local individuals identified by $\delta^{18}O$ values. Similar findings were discussed in Lightfoot and O'Connell (2016) for various archaeological sites around the world. Any original data reported from bone samples were adjusted by +1.4‰ following the approach described in Section 2.6.2 (Webb et al. 2014).

Importantly, $\delta^{18}O$ values were also measured differently across previous studies. Some measured phosphates; some, carbonates. Carbonate $\delta^{18}O$ values originally reported on the Vienna Pee Dee Belemnite (VPDB) scale were converted to the VSMOW scale using the equation: $\delta^{18}O_{VSMOW} = (\delta^{18}O_{VPDB} \times 1.03091) + 30.91$ (Coplen 1988). Phosphate $\delta^{18}O$ values were converted to carbonates on the VSMOW scale using the equation: $\delta^{18}O_p = (\delta^{18}O_{VSMOW} \times 1.0322) - 9.6849$ (Chenery et al. 2012).

3 | Oxygen Isotope Results

We began by evaluating whether $\delta^{18}O$ values covary with the time period at Santa Rita Corozal. If no significant temporal covariance is detected, it is possible to define a single local range to identify non-locals. In contrast, if significant temporal covariance is detected, multiple local ranges would be necessary for each time period to identify non-locals. We find that mean $\delta^{18}O$ values and interquartile ranges are consistent through time (Figure 5), which is corroborated by a Kruskal-Wallis test (chi-squared = 7.637, df = 5, p-value = 0.177), a one-way ANOVA (f-value = 2.144, p-value = 0.083), and a Tukey's test (lowest p-value = 0.110, see Table S5).

Given that there are no statistical differences in $\delta^{18}O$ values between time periods at Santa Rita Corozal, a single local oxygen isotope range is appropriate, here defined as +24.1‰ to +29.3‰. As seen in Figure 5, eight Ancestors out of 85 Ancestors in the study (9%) fall outside the statistically calculated local oxygen range for Santa Rita Corozal and are identified as being non-local (see also Table 3, Table S1). Migration to Santa Rita Corozal is present in every major time period, except the Terminal Classic. This is likely due to the small number of Terminal Classic burials available in the sample ($n = 2$), rather than an absence of influx during the Terminal Classic. Of importance is that these non-local Ancestors came from different geographical areas during different time periods, as evidenced by the $\delta^{18}O$ values either below or above Santa Rita Corozal's local $\delta^{18}O$ range.

Figure 6 shows $\delta^{18}O$ values measured at other sites across the Maya world. We acknowledge this comparison between datasets has limitations due to differences in sample preparation methods, labs used for analyses, and differences in conversion equations available for use (see, e.g., Chenery et al. 2012; Daux et al. 2008; Iacumin et al. 1996; Levinson et al. 1987); however, we made appropriate statistical adjustments (see Section 2.6.3) to publicly available oxygen isotope data to facilitate comparisons, and Figure 6 allows for the visualization of geographic trends in oxygen isotope ratios. Based on the oxygen isotope ranges at these sites, it is possible to estimate the cultural area of origin (e.g., Northern Lowlands, Southern Lowlands, Metamorphic Province, Volcanic Highlands, Maya Mountains), perhaps different regions within a given cultural area (e.g., the Petén Region vs. northern Belize, both located in the Southern Lowlands), and a group of potential sites of origin where comparative data currently exist. Pinpointing a single site of origin, however, is not yet and may not become possible.

Measured $\delta^{18}O$ values of precipitation, surface, and groundwater samples collected across Mexico and Central America change on a SW–NE axis in the Maya world, becoming more positive as you move from the Volcanic Highlands N/NE to the Northern Lowlands (Lachniet and Patterson 2009; Pérez et al. 2011; Sánchez-Murillo and Birkel 2016). Human skeletal elements are more complicated because they have much larger $\delta^{18}O$ ranges and because $\delta^{18}O$ values in humans are affected by various biological, hydrological, and anthropogenic processes. $\delta^{18}O$ values in humans drastically increase from the Highlands to the Petén and northern Belize areas and then slightly decrease as you move closer to the Caribbean coast (Figure 6). The $\delta^{18}O$ range for Santa Rita Corozal is highlighted purple. Gray bars indicate oxygen local ranges for those sites that fall completely within the local range for Santa Rita Corozal, and any potential migrants from these sites are therefore not detectable with a stable oxygen approach. Orange bars indicate potential places of origin for migrants at Santa Rita Corozal with high $\delta^{18}O$ values because their upper bounds include values above the established local range for Santa Rita Corozal. Blue bars indicate potential places of origin for migrants at Santa Rita Corozal with low $\delta^{18}O$ values because their lower bounds include values that fall below the

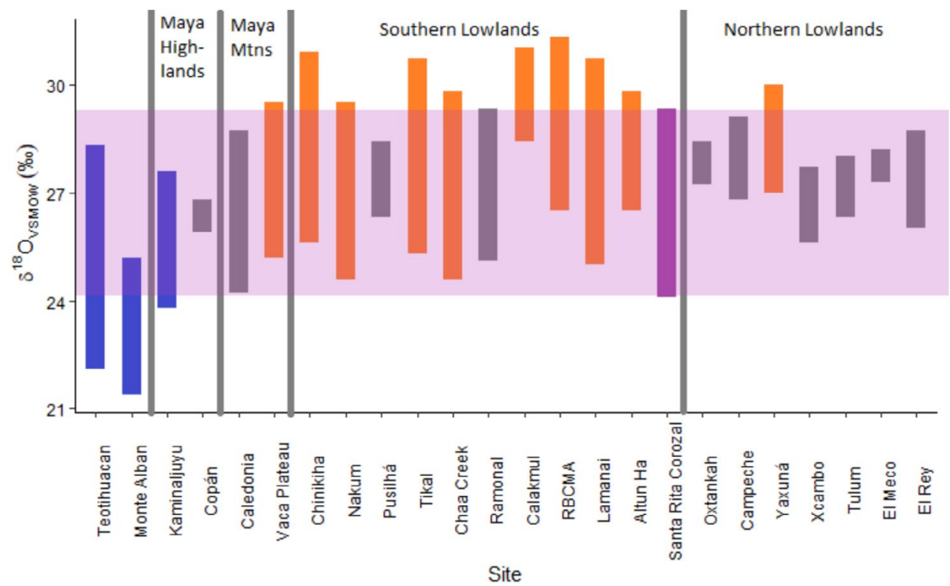

FIGURE 6 | Ranges of local $\delta^{18}O$ values from various ancient Maya archaeological sites arranged by geographic location, SW–NE. Purple bar represents the $\delta^{18}O$ range for Santa Rita Corozal. Orange bars represent sites with local $\delta^{18}O$ ranges that are higher than the local range for Santa Rita Corozal. Blue bars represent sites with local $\delta^{18}O$ ranges that are lower than the local range for Santa Rita Corozal. The purple horizontal bar shows how the local $\delta^{18}O$ range for Santa Rita Corozal compares to other sites in Mesoamerica.
Source: Data from (Freiwald 2020; Howie et al. 2010; Locker et al. 2023; Negrete et al. 2020; Olsen et al. 2014; Ortega-Muñoz et al. 2019, Ortega-Muñoz and Cucina 2021; Price et al. 2012, 2014, Price et al. 2018a, Price et al. 2018b, 2020; Rand 2016; Rand et al. 2020; Sharpe et al. 2022; Sierra Sosa et al. 2014; Somerville et al. 2016; White et al. 1998, 2001, 2002, 2004a, 2004b, 2007; Wright 2012; Wright et al. 2010).

established local range for Santa Rita Corozal (see also Figure 2 for geographic location and Figure 5 for associated chronology).

In assessing the spatial and temporal information for the eight individuals who are non-local to Santa Rita Corozal in this study, it is clear that migrants are drawn from different places across different time periods (Figures 5 and 6, Table S1). Again, while it is not possible to identify a precise place of origin for Ancestors by measured isotope ratios, we can identify general areas from which the Ancestors may have moved (Table 4) by comparing to existing, published datasets. Migrants from the Preclassic and Late Classic came from places with $\delta^{18}O$ values lower than the local range for Santa Rita Corozal. Migrants from the Early Classic and Postclassic came from places with $\delta^{18}O$ values higher than the local range for Santa Rita Corozal.

4 | Discussion

To reconstruct patterns of Maya mobility at Santa Rita Corozal in relation to its social, political, and demographic changes over time, and to gauge potential places of origin for migrants interred at Santa Rita Corozal, we measured stable oxygen isotopes from 96 Maya Ancestors spanning every pre-colonial phase of Maya chronology over a period of nearly three millennia. Based on the knowledge of local Maya people as well as the ethnohistoric, archaeological, and bioarchaeological evidence about the relationships between sociopolitical change and movement, we made four predictions about the migratory history of Santa Rita Corozal that we evaluated using the stable oxygen data generated in this study.

First, based on the archaeological record showing shifting cultural affinities over time at Santa Rita Corozal and the ethnohistoric record documenting population movements in the Maya area, we predicted that migrants would be drawn from different geographical regions across the different chronological phases at the site. The stable oxygen isotope data presented here confirm that non-local individuals were coming from different places and that those places varied through time. In the Preclassic and Late Classic, $\delta^{18}O$ values of non-locals fall below the local range for Santa Rita Corozal. Other sites sharing similar values are generally found in regions with high elevation and include sites such as Teotihuacan, Monte Alban, and Kaminaljuyu (located in the Maya Highlands). Contrary to $\delta^{18}O$ values of earlier periods, non-local individuals recovered from Early Classic and Late Postclassic contexts have higher $\delta^{18}O$ values, indicating that migrants likely came from places of low elevation in the Southern or Northern Lowlands. Published data for sites with more positive $\delta^{18}O$ values than Santa Rita Corozal include Altun Ha, Calakmul, Chaa Creek, Chinikiha, Lamanai, La Milpa, Tikal, and Yaxuna. There are several caveats to consider here. First, many of the potential places of emigration point to sites that were significantly depopulated before the Late Postclassic. Second, surrounding and neighboring areas to depopulated places may have had occupation that has not been excavated, meaning it has no archaeological presence. Third, not all archaeological sites have stable isotope data reported for them, so we are likely missing many potential places of emigration. Finally, there is a lot of overlap between sites, pointing to the complexities of determining a singular point of emigration for non-local individuals. Additional isotopic analyses (i.e., strontium, lead, sulfur) will be useful in helping to identify potential places of origin that have overlapping $\delta^{18}O$ values. It is likely that once these additional isotopic analyses are completed, more non-locals will be observed within the burial population. Regardless of these complexities, our data confirm that non-local individuals came from different places through time.

Second, we predicted a potential influx of non-local people during the Middle Preclassic when the city was first established. This prediction was based in part upon prior archaeological

TABLE 4 | Ancestors identified as being non-local to Santa Rita Corozal based on measured $\delta^{18}O$ values from their dental and skeletal elements. $\delta^{18}O$ values that fall outside the local range for Santa Rita Corozal are bolded. Paired tissues are included when available and when QC checks were met.

Time period	Ancestor ID	Element	$\delta^{18}O$	Potential places of origin
Middle preclassic	SRC 31	Long bone frag.	+25.9‰	Mountainous regions or places of high elevation. Potentially Basin of Mexico or Maya Highlands.
		M1	**+23.3‰**	
	SRC 27	Femoral shaft	**+24.0‰**	Mountainous regions or places of high elevation. Potentially Basin of Mexico or Maya Highlands.
Late Preclassic	SRC 49	M1	**+23.1‰**	Mountainous regions or places of high elevation. Potentially Basin of Mexico or Maya Highlands.
Early Classic	SRC 02	Long bone frag.	**+29.8‰**	Places of low elevation. Potentially Maya Northern Lowlands or Maya Southern Lowlands.
Late Classic	SRC 35	Molar	**+23.1‰**	Mountainous regions or places of high elevation. Potentially Basin of Mexico or Maya Highlands.
Late Postclassic	SRC 12	Femoral shaft	**+30.1‰**	Places of low elevation. Potentially Maya Northern Lowlands or Maya Southern Lowlands.
	SRC 10	M3	**+29.8‰**	
	SRC 70	phalanx	**+29.8‰**	

evidence showing that the site grew from an initial population of approximately 150 residents in the Middle Preclassic to approximately 1000 residents during the Late Preclassic, which could be due to local population growth, migration, or both (Chase 1990; Chase and Chase 2004; Iannone et al. 2014). Given the available sample size that we have, the $\delta^{18}O$ data provided here suggest that migration may have peaked during the Middle Preclassic. The $\delta^{18}O$ data indicate that non-local residents made up 25% of the sampled burial population from the Middle Preclassic and 11% of the sampled burial population from the Late Preclassic. The Middle Preclassic percentage is approximately three times higher than rates of migration during the later time periods. However, the limited samples available from these earlier time periods may be influencing these patterns, and future studies at this and other sites will be necessary to determine whether the finding of high mobility in the earliest phases of the city holds with denser sampling.

Despite the potential impact of sampling bias on rates of migration during the Preclassic at Santa Rita Corozal, previous isotopic studies of migration in other parts of Mesoamerica suggest that our findings are within the range of possibility. For example, similar findings of higher rates of migration during the Preclassic compared to other time periods have been found at other nearby sites in Belize, such as those in the Rio Bravo Conservation and Management Area (Locker et al. 2023). Within this context, our present data may therefore provide some support for the prediction that an influx of migrants occurred as the city was established during the Preclassic phases at Santa Rita Corozal.

Next, given the dramatic change in sociopolitical organization and the remapping of regional networks during the Postclassic evident in the archaeological record, we predicted that the Classic to Postclassic transition would be an inflection point in the number and origins of migrants to Santa Rita Corozal. The Late Classic movement to Santa Rita Corozal occurs around the time when Teotihuacan declines between CE 550–650, and large-scale sociopolitical changes in the Basin of Mexico may have played a role in causing migration throughout Mesoamerica (Clayton 2013; Cowgill 1997; Nichols 2016; Sugiyama et al. 2015). In terms of the scale of migration, our predictions did not necessarily hold for the Postclassic. Rather than migration reaching a peak in the Postclassic, the $\delta^{18}O$ data suggest that while movement occurred during the Late Postclassic, it may have been smaller in scale than earlier time periods. In fact, non-local individuals made up only 8% of the total burial population from the Late Postclassic in our sample, which is substantially less than the levels of migration seen in the Middle Preclassic, when the rate of migration may have been greater at Santa Rita Corozal. More importantly, the rate of migration to Santa Rita Corozal in the Late Postclassic is similar to the rates experienced during the Early and Late Classic periods, indicating that movement to the site appears constant through these periods of time. While this rate may be affected by sampling density, the number of individuals sampled in the Postclassic was the greatest of any archaeological phase in this study yet had fewer migrants than the Preclassic phases. However, if more migration was occurring during this time, it may have been from other places with similar $\delta^{18}O$ values (i.e., other sites from the Northern and Southern Lowlands).

Our results do offer some support for the prediction of an inflection point in the geographic origins of migrants to Santa Rita Corozal in the Postclassic and help to inform multiple possible scenarios indicated by the archaeological and ethnohistoric records. On the one hand, the presence of Mixteca-Puebla murals on Mound 1 at Santa Rita Corozal and other trends in material culture indicate ties to the Northern Lowlands and Mexico. Multiple Postclassic burials from Santa Rita Corozal have mortuary items that align with the northern Yucatán (Chase and Chase 2008). Additionally, Late Postclassic obsidian deposits show that Santa Rita Corozal was part of a broader trade and exchange system with central Mexico (Seidita et al. 2018). Therefore, it is possible that migrants were arriving at Santa Rita Corozal from the Northern Lowlands and had contact with Mexico in the Late Postclassic. However, most of the sites in the Petén and Southern Lowlands were depopulated in the Terminal Classic, though there was some continued occupation into the Postclassic periods along coastal, river, lacustrine, or lagoonal spaces, such as the Petén lakes region (Chase and Rice 1985), northwestern Belize (Houk et al. 2008), Lamanai (Graham 2004), and Colha (Barrett and Scherer 2005). Therefore, it is possible that migrants may have arrived at Santa Rita Corozal from these regions. The ethnohistoric record provides additional perspectives on potential population dynamics during this period. Specifically, the *Chilam Balam* describes multiple movement events from the Petén and the Gulf of Mexico to the Northern Lowlands, beginning around CE 692 (Edmonson 1982, 1986). These initial movements are followed by multiple movement events throughout the Northern Yucatán, return migration events back to the Petén, and later from the Petén back to the Northern Lowlands, beginning as early as CE 948 and as late as CE 1539. Taken together, there are multiple and potentially overlapping scenarios for migration to Santa Rita Corozal.

The oxygen isotope data collected in this study therefore support a complex interplay of the scenarios presented by the archaeological and ethnohistoric records. Based on $\delta^{18}O$ values, one potential place of origin for Ancestor SRC 70 from the Late Postclassic is Yaxuna (Price et al. Price et al. 2018a, 2018b), located some 18 km SW of Chichén Itzá in the Northern Lowlands. If this was the site of origin for this non-local Ancestor, the narrative from the *Chalam Balam* books fits rather well. So too are these cultural links to the Northern Lowlands in Mexico apparent in the Postclassic archaeological assemblage. On the other hand, Ancestors SRC 10 and SRC 12 have $\delta^{18}O$ values that indicate they may have come from somewhere in the Southern Lowlands. Their values match published datasets available from sites such as Calakmul (Price et al., Price et al. 2018a, 2018b), Lamanai (Howie et al. 2010), La Milpa (Locker et al. 2023), Tikal (Wright 2012), or other sites representative of western Belize and the Petén. Again, there is a possibility that Ancestors who moved to Santa Rita Corozal may have come from other places that do not have data available in isotopic studies. Given the similarities in some Late Postclassic materials, it is conceivable that people from Santa Rita Corozal were able to trade for luxury items from across Mesoamerica. What these data do inform, however, is that the immigrants from the Late Postclassic came from different places than immigrants from the Preclassic, which supports our prediction of an inflection point. Future analyses will further evaluate movement from locations with overlapping $\delta^{18}O$

values by using strontium isotopes. This will help clarify the potential relationships between recovered burial material remains, the ethnohistoric record, and the $\delta^{18}O$ values from this study.

In thinking of Santa Rita Corozal as being positioned as a bridge between two major cultural regions of the Maya area (i.e., the Northern Lowlands and the Southern Lowlands), it makes sense that traditions from both areas would be present and that their relative composition would shift throughout time along with sociopolitical and economic arrangements. Santa Rita Corozal likely did not fall under the realm of polities from either cultural region and maintained its autonomy through time (Iannone et al. 2014). This ability to interact within multiple political spheres, shift, and realign itself may have been advantageous for Santa Rita Corozal during the Late Postclassic as it was able to attract populations leaving these spaces. Already a space embedded within a broad trade and exchange system, where Santa Rita Corozal controlled waterway access (Awe et al. 2020; Chase and Chase 1989, 2004, 2005, 2020), the site was able to flourish during multiple periods where sociopolitical and environmental change disrupted other areas of the Maya world. For example, unlike other sites in the Southern Lowlands, Santa Rita Corozal did not decline in the Postclassic, but rather tripled its population (Chase 1990; Chase and Chase 2004; Iannone et al. 2014) and claimed the seat of power for the Late Postclassic Province of Chetumal (Awe et al. 2020; Chase and Chase 1985, 1988; Iannone et al. 2014). Furthermore, because immigrating groups of people came from multiple geographic regions throughout time, the site was already known to external groups of people and could attract new immigrants due to established migratory networks already in place.

Finally, because Santa Rita Corozal controlled an active trade port within such a broad network, it could continue to persist by relying upon trade relations that existed outside of the control of broader regional powers. In other words, Santa Rita Corozal did not rely on its subordinance to other spaces and places to trade and thrive. Rather, it maintained control of its own relationships for trade and exchange outside of the political spheres to the north, west, and south. This allowed it to shift its sociopolitical and economic relationships in periods of profound transformation across the broader Maya world. In other words, if sites in the Southern Lowlands experienced decline, Santa Rita Corozal could turn its attention to the south and north. When sites in the Northern Lowlands experienced turmoil in the Late Postclassic, Santa Rita Corozal could reopen trade with sites in the Petén. In this manner, it could persist despite broader sociopolitical transformation because it existed outside regional sociopolitical control.

5 | Conclusion

The Maya were and continue to be a people of movement. In reconstructing patterns of migration at Santa Rita Corozal, we identified eight individuals as being clearly non-local (although others may have been as well). Oxygen isotope data presented here show that movement to Santa Rita Corozal occurred throughout time and that, depending on the time period, places of origin shifted. These shifts coincide with the ethnohistoric records detailed in the *Chilam Balam* books as well as the archaeological record of Santa Rita Corozal. To better flesh out some of the complexities of these movements throughout time and to better constrain geographic places of origin, future research will include strontium, lead, and sulfur isotopic analyses of the currently sampled and future sampled Ancestors from the site. Because Santa Rita Corozal bordered the Southern and Northern Lowlands, it had no permanent alliance to, or rather was never under the direct control of, polities to its north, west, or south. Instead, Santa Rita Corozal existed within its own autonomous sphere and could attract people from different places throughout time. The sociopolitical flexibility seen at Santa Rita Corozal may have contributed significantly to the persistence of the site through time and across the Classic to Postclassic transition. This study therefore provides important diachronic insights not only into three millennia of Maya movement in response to sociopolitical change at Santa Rita Corozal but also how context-specific geopolitical relationships have shaped demographic processes at this site differently relative to others in the Maya world.

Author Contributions

Angelina J. Locker: conceptualization (equal), data curation (lead), formal analysis (lead), investigation (lead), methodology (lead), supervision (lead), validation (lead), visualization (lead), writing – original draft (lead), writing – review and editing (lead). **Diane Z. Chase:** conceptualization (equal), funding acquisition (equal), resources (equal), writing – review and editing (equal). **Arlen F. Chase:** conceptualization (equal), funding acquisition (equal), resources (equal), writing – review and editing (equal). **Adrian S. Z. Chase:** writing – review and editing (equal). **Adela Pederson Vallejos:** conceptualization (equal). **Genara Cano:** conceptualization (equal). **Roy Rodriguez:** conceptualization (equal). **To'one Masehualoon NGO:** conceptualization (equal). **Melissa Badillo:** resources (equal). **Lilian J. Baker:** methodology (supporting). **Tiffiny A. Tung:** funding acquisition (equal), resources (equal), writing – review and editing (equal). **Rick W. A. Smith:** conceptualization (equal), funding acquisition (lead), project administration (lead), resources (equal), supervision (equal), writing – original draft (supporting), writing – review and editing (equal).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that supports the findings of this study are available in the Supporting Information of this article.

Endnotes

[1] We use the term "Ancestor" throughout this manuscript to denote individuals recovered from archaeological excavations at Santa Rita Corozal (SRC). This terminology reflects conventions advocated by Indigenous scientists (e.g., Claw et al. 2017; Fox 2021) as well as decisions made in connection with Maya community partners in Belize about how to speak of persons interred at SRC. Collectively, this terminology is intended to express our understanding that people recovered from the archaeological excavations at SRC are not merely material *representations* of once living persons, but *are* themselves persons to our Maya collaborators, the wider Maya communities living in northern Belize, and ourselves. We therefore often use "Ancestor" as a qualifier of, or in substitution of, conventional terminology such as "collections", "remains", "materials", etc. Further, as there are many usages and meanings of the term "Ancestor" both colloquial and scientific, we broaden our usage of the term from the confines of descent.

While an Ancestor in our usage may include a person from whom living Maya people descend (whether or not this is knowable), this term may also include ancient Maya persons whom living Maya peoples and our collaborators regard as sacred, with or without the condition or knowledge of descent.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.