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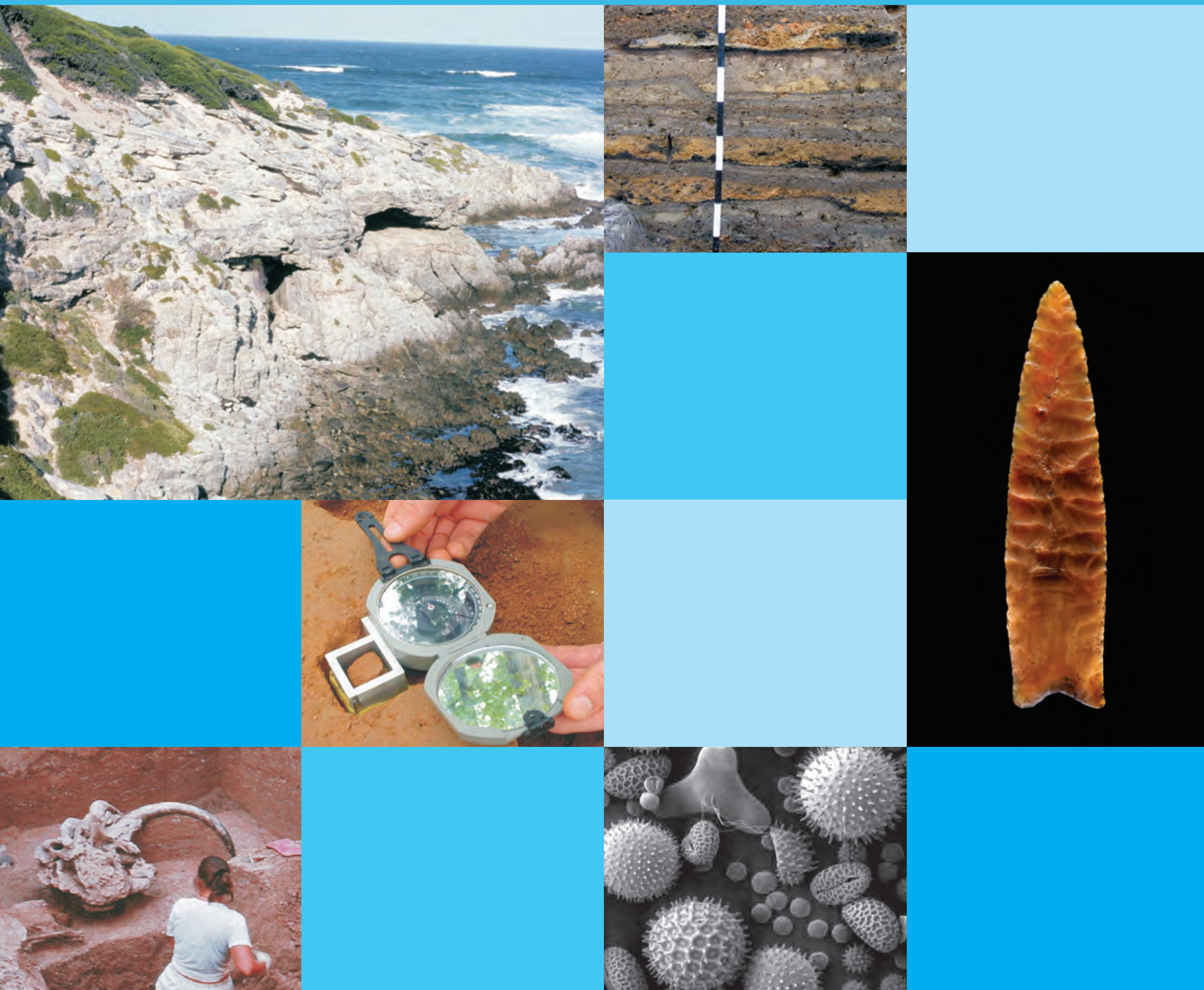

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RESEARCH ARTICLE OPEN ACCESS

The Flooding of Lagash (Iraq): Evidence for Urban Destruction Under Lugalzagesi, the King of Uruk and Umma

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ABSTRACT

High-resolution remote sensing, magnetometry, and trench stratigraphy identify a significant flood event at Lagash (modern Tell al-Hiba) during the late Early Dynastic period (ca. 2400–2350 BC). Satellite imagery and magnetometry reveal a 90-meter-wide meander belt—3–15 times broader than documented canals—adjacent to primary temple districts. Test trenches further exposed over one meter of flood-deposited silt covering existing architecture. Optically stimulated luminescence dating (central age: 2390 ± 220 BC) aligns closely with radiocarbon dates obtained from contemporaneous burn layers elsewhere on the site. Displaced artifacts, including an inscribed foundation nail from the reign of King Enannatum I (ca. 2425 BC) and diagnostic ceramics, confirm that the flood occurred after his rule but before Akkadian occupation. Integrating geomorphic, sedimentological, and textual evidence, we propose that the flooding was triggered when Lugalzagesi of Uruk-Umma (reigned ca. 2350 BC) intentionally breached or precipitated the failure of Lagash's principal canal embankments during or immediately following his documented attack on the city. This event illustrates how critical infrastructure for irrigation and transportation could be deliberately exploited to exacerbate the environmental and economic impacts of warfare. By closely associating the flood, the military siege, and subsequent demographic decline within a single generational timeframe, our study refines third-millennium BC Mesopotamian chronology and underscores the interconnected roles of hydrology, conflict, and urban resilience in early urban societies.

> *Sans tomber dans un déterminisme étroit, on peut quand même affirmer que l'histoire de l'Irak ne sera vraiment connue que le jour où, parallèlement au déroulement des faits politiques, on retracera la chronologie des déprédations occasionnées par le Tigre et l'Euphrate.*
>
> - Etienne de Vaumas 1958: 248

1 | Introduction

Water has been a persistent driver of societal conflict throughout history (Gleick and Shimabuku 2023, and references therein), particularly in arid floodplain regions where irrigation-dependent resources span political boundaries. Nowhere was this more evident than in 3rd-millennium BC

Mesopotamia. The earliest known example of interstate warfare recorded in written documents, the Lagash–Umma Border Conflict (LUBC), emerged around 2500 BC in such an environment. Cuneiform inscriptions from these rival city-states, located near modern-day Shatra in south-central Iraq, chronicle a prolonged struggle over irrigated land and water access (Cooper 1983, and references therein). This contest underscores the deep entanglement of state-level political authority with control over hydrological infrastructure in early complex societies.

Lagash (modern Tell al-Hiba) and Umma (modern Tell Jokha) were both key city-states in the lower Tigris delta, with Lagash positioned downstream of Umma (Figure 1A–C). Their rivalry, which spanned multiple generations during the Early Dynastic III period (c. 2500–2350 BC; Early Dynastic is labeled "ED" hereafter), centered on the Gu'edena, or "Edge of the Plain," a fertile, well-watered region located just upstream of the ancient estuary of the Persian Gulf (Figure 1B). In a region where rainfall was insufficient for agriculture, irrigation was essential, yet Sumer's clay-rich soils were also vulnerable to both flooding and salinization (Potts 1997, 6–29, and references therein). As a result, institutionalized water management—for irrigation, flood control, and transportation—was both a catalyst for conflict and a foundation for intercity cooperation from the earliest days of Sumerian civilization (e.g., Adams 1981; Nissen 2015; Schrakamp 2015).

After protracted cycles of conflict, Umma ultimately gained the upper hand. Around 2350 BC, Lugalzagesi—having first consolidated power in Umma and subsequently in Uruk—launched a devastating assault on Lagash and its irrigated hinterland. A contemporary and unique historical text, referred to variably as *The Sin of Lugalzagesi* or *The Destruction of Lagash*, portrays the attack not simply as a political conquest but as a sacrilegious rupture of cosmic order (Powell 1996; Thureau-Dangin 1904; see sect. 2.2). In the aftermath of this catastrophe, Lagash's ruler, Urukagina, abandoned the title "King of Lagash" in favor of "King of Girsu," reflecting a shift in the state's political and religious center. Archeological surveys have likewise described a dramatic population decrease around this same period at the site (Carter 1989–1990; Goodman et al. 2022), possibly reflecting population relocation to Girsu, roughly 25 km to the north (Lambert 1966). References in cuneiform texts to the concurrent transfer of state cults (Falkenstein 1966, 21) further underscore a deliberate recalibration of dynastic power and ritual authority upstream to higher ground.

However, the reasons behind this dramatic socio-demographic shift, including the physical abandonment of Lagash and the potential relocation of its political capital, remain debated (Bahrani 1989, 176). Hansen (1970, 244) cautiously linked these processes to the rising power of Akkad in the north. Well before modern remote-sensing, Falkenstein (1966, 20–21) working from topographic maps, anticipated environmental stress: he noted that Gudea (c. 2100 BC), who ruled the city-state's second dynasty some two centuries later, described Nigin's temple—which was located close to the city of Lagash—as "a mountain rising out of the water," implying recurrent waterlogging in the region.

New geoarchaeological data corroborate and sharpen that hypothesis. Magnetometry, UAV imagery, and trench stratigraphy document a 90 m-wide meander sweep emanating from Lagash's main temple district (Figure 2A,B). Point- and counter-point bars, > 1 m of water-laid silt, displaced artifacts (e.g., an Enannatum I foundation nail), and tightly clustered OSL ages indicate a single, high-energy flood post-dating the city's foundation yet pre-dating Akkadian occupation. The sweep is an order of magnitude wider than known urban canals (6–30 m) and exhibits fluvial scroll-bar morphology unknown in engineered channels.

We propose that the flood was triggered when Lugalzagesi's forces deliberately breached one of Lagash's primary canal embankments—or indirectly caused its neglect by displacing the local population—weaponizing the city's own hydraulic infrastructure to amplify the assault's destructive impact. By integrating textual, geoarchaeological, and geophysical datasets, this study (i) reconstructs the mechanics and timing of Lagash's catastrophic flood, (ii) situates the event within a broader pattern of conflict-induced hydraulic failures, and (iii) re-evaluates the entropic vulnerabilities of early Mesopotamian urbanism (Algaze 2018). Ultimately, these findings illuminate how tightly coupled water systems, once compromised, could precipitate rapid demographic and political reconfiguration—insights that resonate far beyond the Sumerian plain.

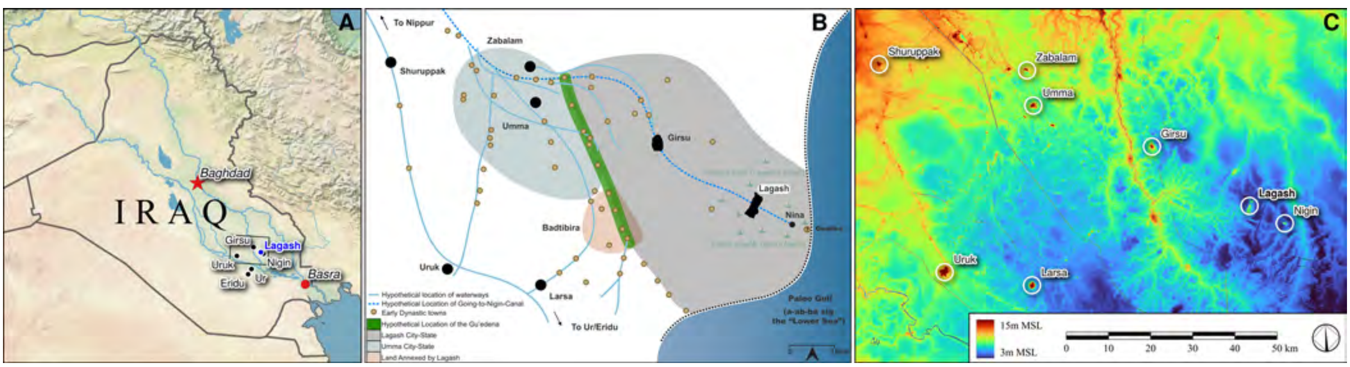

FIGURE 1 | (A) Location of sites mentioned in text (*background imagery made with Natural Earth*). (B) Reconstruction of historical/political geography and waterways of Sumer in the ED period with focus on Lagash. Historical geography is hypothetical, based on textual analyses (modified by Rey 2016, fig. 24, p. 55). (C) Digital elevation model (showing the downward slope from northwest to southeast in the same area of (B) (Copernicus DEM https://doi.org/10.5270/ESA-c5d3d65).

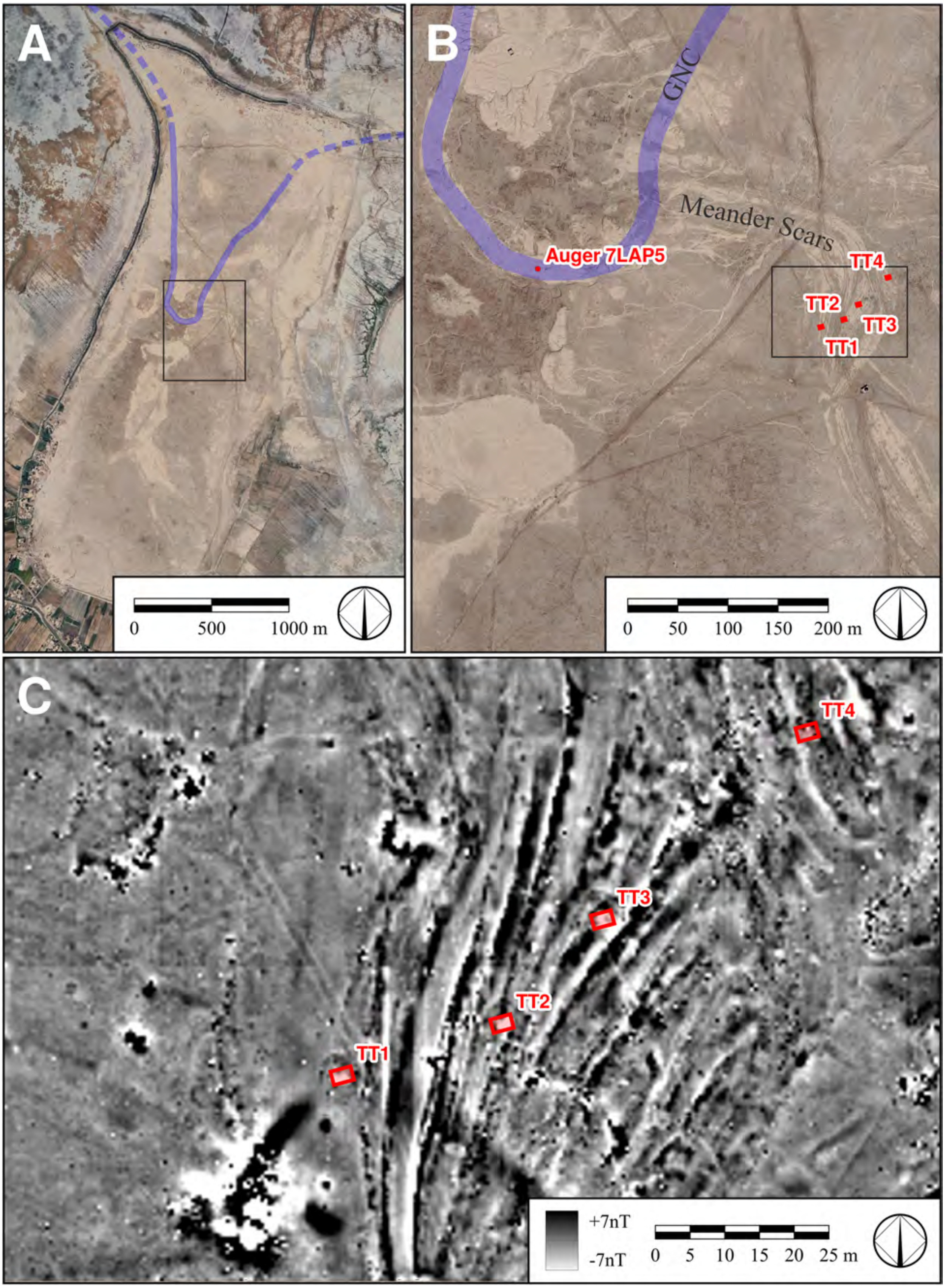

FIGURE 2 | (A) Satellite image of Tell al-Hiba with reconstructed GNC. (B) Detail of (A) showing location of test trenches, auger, and meander scars. (C) Magnetogram of meander scars and test trenches (Background imagery for 2a and 2b is Google Earth image 2024 Airbus).

2 | Background

2.1 | Water and Irrigation in Mesopotamia

Centrally maintained waterworks underpinned the expansion of urban populations in 3rd-millennium BC Mesopotamia (Nissen 1976). Hydraulic infrastructure associated with managed waterways facilitated transportation, ensured reliable irrigation and improved stormwater management, particularly during the spring flood season (Rost 2017). Engineered intercity rivers provided conduits for political pageantry and public ritual, as well as institutional exchange and redistribution (Beld 2002; Matthews 1993; Ristvet 2014). Geoarchaeological and geophysical studies from contemporary urban centers such as Uruk, Fara, and Girsu exemplify the deeply embedded relationship between water and urban life in Sumer, revealing Venice-like settlements crisscrossed by canals (e.g., Egberts et al. 2023; Hahn et al. 2022; Fassbinder et al. 2019). Off-site vehicle surveys further demonstrate how these highly localized water networks are connected at regional scales (Adams 1981).

Intensive exploitation of the Mesopotamian plain for agriculture has always demanded cooperation among shared water users, posing institutional challenges for long-term subsistence success (Adams 1981, 6–7). By the ED III period, coordination involved the construction and maintenance of water control infrastructure such as canals, dikes, and regulators, and brought associated labor organization and control structures (Schrakamp 2018). Thus, irrigation systems promoted federative activity (Fernea 1970) but also heightened risks of system-wide agricultural collapse—especially as systems became increasingly centralized and interdependent over time (e.g., Adams 1978; Gibson 1973, 1974). The demand for sociopolitical integration, then, was crucial to the survival and prosperity of early urban communities, just as it remains today (Fernea 1970, 48–54; Poyck 1962; Steinkeller 1999, 304).

2.2 | Political and Conflict Setting

The state of Lagash encompassed the urban settlements of Girsu, Lagash, and Nigin, along with a network of smaller settlements connected by waterways (e.g., Lecompte 2015; Figure 1B). Texts report that Ur-Nanshe (c. 2500 BC), the founder of the city-state's first dynasty, constructed the Going-to-Nigin Canal (hereafter, GNC), a primary branch of the Tigris that flowed northwest-southeast from Girsu through Lagash to Nigin before reaching the sea (Carroué 1986; Figure 1B). Notably, the GNC connected and flowed through the city-state's primary population centers (see Carroué 1986, 23, Figure 2).

Practically speaking, the LUBC involved competition for control of this Tigris branch and its feeder canals downstream from Umma and Zabalam (modern Tell Ibzeikh), the chief cities of the Umma city-state (Figure 1B). Historical sources represent the conflict as a battle between the city-states' rival gods over their "favorite fields," critical agricultural lands whose god-granted fertility maintained cosmological order (Winter 1985). Texts, mostly from Girsu, illustrate extraordinary state investments in hydrological infrastructure at precisely this moment, including the construction of extensive bank fortifications and dikes to secure water access and differentiate territorial boundaries (Rey 2016, 61–62; Schrakamp 2018). Many of these features were associated with "frontier temples" that constituted a "cultic topography" of sacred waterways subject to repeated enemy attack, but they also involved the construction of canals and water regulators within cities (Rey 2016, 53–63; Schrakamp 2018).

During the ED III period, Lagash's state institutions oversaw vast tracts of irrigated land, supporting exceptional agricultural productivity throughout the region (Diakonoff 1956, 174; Maekawa 1974; Westenholz 2002, 26). However, Umma's advantageous upstream position left Lagash's waterscape increasingly vulnerable to human interference. Around 2450 BC, Eannatum, Lagash's ruler, established a "boundary canal" with a ~1300-meter-wide buffer zone in the Gu'edena to deter Umma's expansionary goals. Lagash's side featured major earthworks, religious shrines, and fortified outposts, along with the core of the state's hydrotechnical infrastructure (Rey 2016).

According to Lagash's sources, Umma's rulers repeatedly escalated tensions by attempting to destroy or divert the boundary canal, a critical lifeline for Lagash's agricultural economy. Based on an analysis of irrigation terminology in cuneiform sources, Pemberton et al. (1988) argued more specifically that the LUBC had been fought over the placement of embankments or bunds (Pemberton et al. 1988). In one text, Lagash's ruler, Eannatum, forces Umma's ruler to take an oath not to interfere with his city-state's "dikes and ditches" (Schrakamp 2018, ft. 142). Not long after, another Lagashite ruler, Enmetena (c. 2400 BC), indicates that Umma's leader "had the water go out" of the city-state border embankments of Ningirsu and Nigin (Schrakamp 2018, 148). Critically, when Lugalzagesi led his final march on Lagash, his forces devastated key waterways as they crossed the Gu'edena before sacking the city itself (Rey 2016, 65–66).

We return now to the *Sin of Lugalzagesi* tablet introduced above, because its terse narrative anchors the chronology of the events recovered in our trenches. Historical evidence for the devastation derives directly from this text, which describes the sacking of named temples, the removal of cultic treasures, and the burning of ripened grain in surrounding fields (Powell, 1996). Read literally, mature cereals place the attack in the spring, when the Tigris and Euphrates reach their annual flood peaks (Wilkinson 2013). That timing is critical: saturated floodplains and high-stage rivers would have left Lagash acutely vulnerable; even a minor levee breach—or deliberate sabotage—could have redirected floodwaters that magnified the human-wrought destruction (Morozova 2005, 2025).

2.3 | Archeological Background and Historical Geography

Our understanding of Lagash's historical geography relies heavily on textual sources, particularly tablets from Girsu. Jacobsen (1958, 1969) conducted a vehicle survey of the Lagash countryside to identify key waterways known from texts, including the GNC, as well as former towns and villages. More precise locations of historical sites and features have emerged through recent advances in textual and remote-sensing analyses; however, these identifications remain tentative until verified through on-the-ground investigations (e.g., Hritz 2021; Rey 2016; Steinkeller 2001).

Exploratory soundings at Lagash in the 1880s identified pockets of extensive ash layering at and near the surface of the site, leading to its characterization as a sprawling necropolis (Ashby 2017, 74; Huh 2008; Koldewey 1887, 430). However, Jacobsen (1958) survey overturned this initial hypothesis. Based on an inscribed surface find, he proposed that, rather than a community burial ground, the site was ancient Lagash. Later research, led by the Metropolitan Museum/New York University (1968–1990), confirmed Jacobsen's supposition. Those investigations focused on temple precincts (Areas A and B), an administrative complex (Area G), and a royal workshop (Area C) (see references in Ashby and Pittman 2022; Pittman and Ashby 2022; Figure 3).

Current data suggest that Lagash exceeded 400 ha of dense settlement by the mid-third millennium BC (McMahon et al. 2023; Carter 1989–1990). During this period, interstate conflict intensified, as evidenced by texts and the construction of monumental city walls. At the same time, sources indicate that Lagash competed for resources with—and defended itself against—rival states such as Uruk, Umma, and Elam (Cooper 1983, 8–9; Grégoire 1962). Following the city's sharp population decline at the end of ED III, as highlighted by sitewide survey results, subsequent occupation was largely restricted to Area B, the "Bagara of Ningirsu," a temple complex dedicated to the city-state's chief deity (Carter 1989–1990). By the early 2nd millennium BC, settlement at Lagash remained insignificant and was followed by brief periods of minor inhabitation during subsequent Kassite (1531–1155 BC) and later Islamic occupations (Zimmerman 2023).

2.4 | The Intracity Flood Feature

High-resolution satellite and drone imagery clearly depicts a belt of arcuate ridges—textbook meander scroll bars—cutting through the heart of Lagash (Figure 2B). Although Hammer et al. (2022; Hammer et al. 2022) identified this geomorphic feature as the intracity reach of the GNC, its geometry, subsurface stratigraphy, and geophysical signatures indicate that it represents a late avulsion event (see Section 4, below).

On the neighboring plains of Girsu and Nigin, confirmed segments of the GNC appear as straight to gently curving corridors approximately 15–30 m wide, bounded by pale, slightly elevated embankments characteristic of constructed Mesopotamian canals (Rey 2016; Egberts et al. 2025; Nadali and Polcaro 2018). In contrast, the Lagash scroll-belt expands dramatically to nearly three times this width (~90 m), displaying nested scroll and counter-point bars consistent with uncontrolled fluvial migration encountering erosion-resistant banks (Sylvester et al. 2021). Crucially, high-resolution satellite imagery suggests that the narrow, embanked canal segment documented by Hammer north of Area B continued on a straight, northerly trajectory (Figure 2A), whereas the meander scrolls diverge sharply eastward (Figure 2B)—a pattern precisely indicative of levee failure.

Recent sedimentological data further clarify this scenario. The Lagash Archeological Project (LAP) placed a 6 m auger, labeled Auger 7LAP5, atop the putative canal berm (31.419340° N, 46.410814° E) in spring 2025 (Figure 2B). This auger, which employed an Edelman-type head and recovered sediments in 20 cm intervals, identified a clear tripartite stratigraphic sequence. Below 2.4 m of sterile eolian sand, indicative of abandonment, a structureless gray-brown silt was identified from 240 to 480 cm depth. This silt layer matches precisely—in texture, color, and elevation—the silt facies documented extensively in Test Trenches 1 through 4 (Test Trenches 1 through 4 are hereafter labeled "TT1" and following), and is consistent with rapid deposition during a high-energy flooding event. Beneath this deposit, sediments between 480 and 600 cm depth transition into silty clays containing abundant pottery, charcoal, and faunal remains, representative of active canal use before flooding. Thus, the stratigraphic sequence confirms canal abandonment and subsequent flood-driven avulsion, with flood deposition postdating canal use.

We hypothesized that this event involved two distinct stages. Initially, a well-regulated segment of the GNC conveyed water and facilitated traffic along a carefully engineered alignment. Subsequently, a catastrophic breach—possibly due to deliberate sabotage or maintenance neglect—redirected the canal's flow, carving out the meander scroll belt and depositing the extensive silt layer clearly in overhead imagery. Hammer's drone-based reconstruction accurately captures the width and layout of the pre-avulsion canal segments; however, her interpretation conflates the later avulsion channel with intentional canal construction, obscuring the true nature and consequences of the flood event. The geoarchaeological, stratigraphic, and geophysical data detailed below position this hydraulic reorganization firmly within the broader historical context of Lugalzagesi's assault and the subsequent urban and ecological transformations at Lagash.

Historical texts consistently underscore Lagash's intensive investment in dikes and embankments to maintain canal navigability and protect low-lying urban districts from inundation (Rey 2016, 34). Allowing a 90 m-wide urban canal to become unmanaged is implausible, as this would have led inevitably to flooding, erosion, excessive sedimentation, and structural damage downslope—precisely the outcomes city managers sought to avoid (Adams 1981, 20; Wilkinson et al. 2015; Algaze 2018). Indeed, Adams (1981, 8) emphasized that meander sweeps of this magnitude were relatively rare on the Mesopotamian plain, underscoring the unexpected nature of such a feature at Lagash, especially postdating urban foundation.

3 | Materials and Methods

In fall 2022, the LAP undertook geoarchaeological trenching to investigate this water-formed feature. A magnetometer survey followed the discovery of cultural material immediately underlying water-laid silt. This study was conducted in collaboration with Iraq's State Board of Antiquities and Heritage (SBAH), the University of Pennsylvania, and the University of Pisa. Below, we provide physical, ecofactual, artifactual, and chronological evidence of intracity flooding at Lagash during the late ED period.

A four-trench transect excavation (each trench 3 × 2 m) investigated the water-formed feature in an area 500 m due west of

FIGURE 3 | Satellite image of Lagash with indication of NYU/Metropolitan museum areas (Background imagery for 2a and 2b is Google Earth image 2024 Airbus).

Area B (Figure 2). TT4 was positioned on a slightly elevated rise, suggesting prior settlement activity. Test trenches were excavated until cultural materials were encountered, at which point excavation ceased. Representative stratigraphic sections from each test trench, in addition to Auger 7LAP5, are provided in Figure 4. Representative photographs of each test trench are provided in Figures S1–S4. Details on geophysical and aerial mapping methods and instruments are also available in the Supplementary Materials.

The excavations aimed to expose sedimentary sections, characterize relevant facies (lithology, textures, and structures), and determine the timing of fluvial bar formation. Color and texture variations in floodplain sediments are robust indicators of past and present ecological conditions across the region (Wilkinson 1990). To establish the fluvial feature's chronology, we employed optically stimulated luminescence (OSL) dating, which determines the time elapsed since mineral grains were last exposed to sunlight or sufficient heating. OSL samples were collected in light-tight containers, prepared at Coastal Carolina University, and analyzed for fine-silt (4–15 μm) and very fine sand (63–125 μm) quartz at the University of Salzburg in Austria following standardized sample preparation and data processing procedures (see Supplementary Materials).

4 | Results

Trenches TT1 through TT3 revealed two distinct facies. The uppermost layer consisted of an extensive gray-brown silt deposit with occasional laminations of ashy debris and mudbrick, capped by a duricrust rich in white-gray gypsum. Beneath this lay a dense red clay layer that extended to the base of each trench (see Figures S1–S3). TT4, in contrast, contained cultural material, including a badly eroded unbaked mudbrick wall running north to south in its western section, shallowly buried at just 20 cm

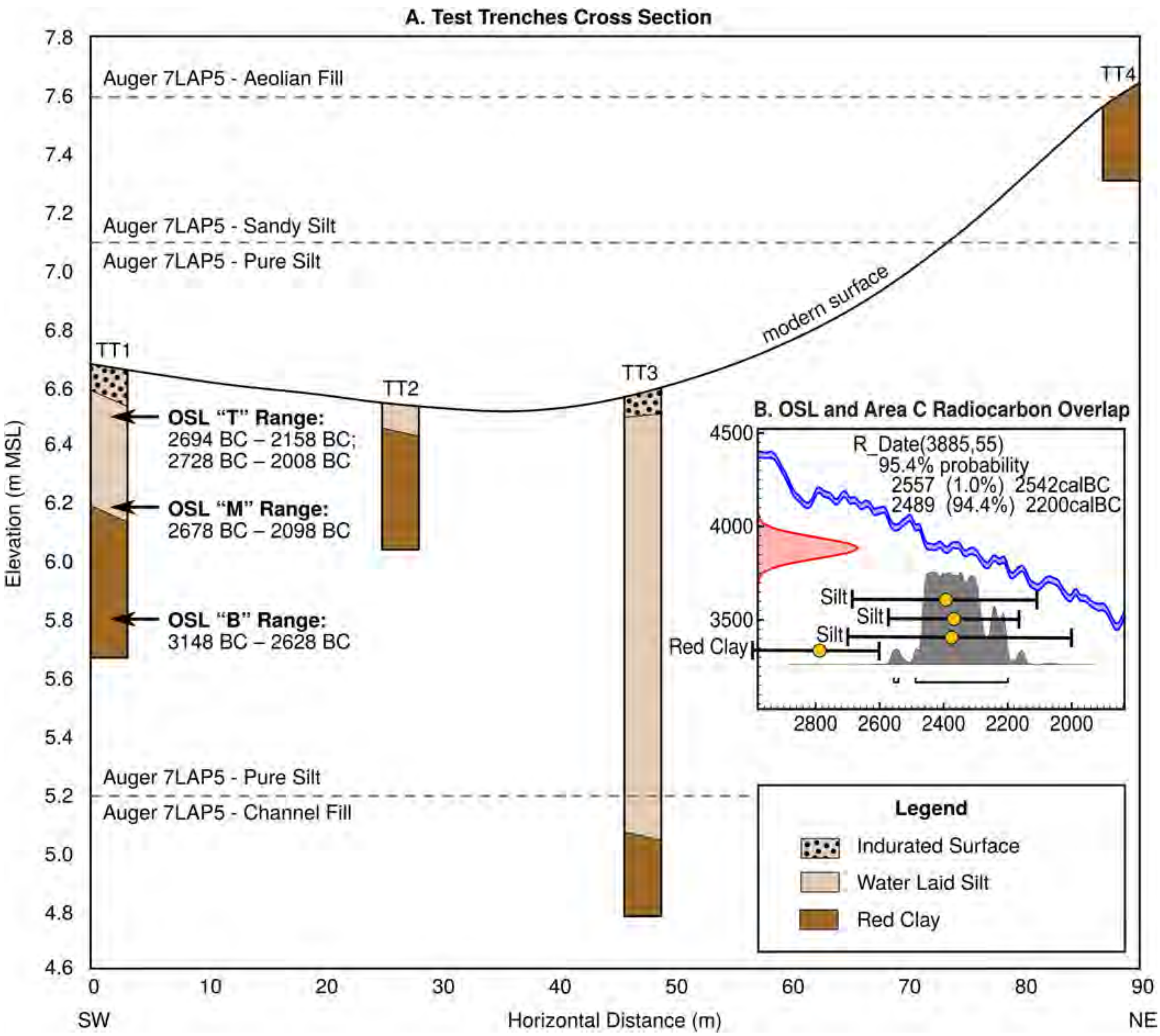

FIGURE 4 | (A) Cross-section with representative facies across Test Trenches, including Auger7LAP5 with indications of OSL dates by depth in TT1. (B) OSL and Area C radiocarbon overlay (Bronk Ramsey 2009; Reimer et al. 2020).

below the surface (Figure S4). While the absence of diagnostic artifacts and the wall's limited depth preclude further detailed discussion of TT4, we will note that the fluvial signature's reach at that elevation, visible in satellite though ephemeral in excavation and magnetometry, reinforces our interpretation of an energetic flood event (see Section 4, below).

The upper silty facies in TT1, TT2, and TT3 varied in thickness, ranging from 20 cm in TT2 to just over a meter in TT3, exhibiting inclined stratification characteristic of point and counterpoint bars. Cultural materials found beneath the silt facies suggest that the underlying red clay layer is anthropogenic. In TT2, we recovered an inscribed clay nail of Enanatum I, a king who ruled Lagash ca. 2425 BC (Figure 5), embedded in the silt matrix ~15 cm below the surface. Carter (1989–1990, 62) survey documented a matching copy of this nail ~200 m to the northwest, while Zimmerman (2023) survey located yet another copy ~725 m north northwest, suggesting that floodwaters displaced these objects from a shared origin.

Excavations in TT1 revealed sections of pisé architecture, while work in TT3 extended to a cultural surface sloping from 1.5 to 1.7 m below plain level. There, a shallow conical vessel was recovered face-down near a deposit of melted mudbrick (Figure 6A,B). This vessel corresponds to Renette's HB-1a type, which is most frequently attested at Lagash in late ED III contexts (Gruber 2015; Pizzimenti 2020; Renette 2021, 34–35, 190–192, Plates 15–17). Furthermore, disarticulated mudbricks embedded within the silt layer across multiple sections of the trench indicate episodes of rapid fluvial deposition (Figure S3).

Several fully articulated adult specimens of *Unio tigridis*, a freshwater mussel species, were recovered from excavation and stratigraphic sections of the silt layer in TT1 and TT3. This species is commonly found in freshwater rivers and lakes throughout the region (Plaziat and Younis 2005). However, *Unio tigridis* presents challenges for radiocarbon dating due to poorly resolved reservoir effects and was, therefore, excluded from dating analysis (Egberts et al. 2023; Geyer and Sanlaville 1996, 397, tab. 2). Notably, the predominance of fully articulated specimens is significant, as under normal conditions, post-mortem taphonomic processes typically lead to shell disarticulation. This suggests that live mussels were transported downstream by floodwaters following an upstream canal breach and rapidly buried before natural decomposition and disarticulation could occur.

4.1 | Chronology

Several intact OSL samples were collected from TT1, which provided sufficient depth for hammer-driven sampling (Figure S1). Given geographical proximity and consistent stratigraphic sequencing across all trenches, as well as interpretations of aerial imagery, we infer that TT1 provides a representative chronology for the broader fluvial feature under study. As expected, OSL dates increased with depth (Table 1; Figure 4). Both dates from the silt layer, including the upper gypsum crust, are statistically identical, yielding a median age of ~2394 BC with an error range of ±220 years. The lowest OSL sample, taken from the red clay layer approximately one meter below the current plain level, produced a date of ~2888 BC. Despite the relatively large error margins inherent to OSL dating, the tight internal chronology in the silt facies reinforces our interpretation of rapid and energetic fluvial sedimentation.

4.2 | Geophysical Evidence

Relict scroll bars visible in the magnetogram and satellite imagery run approximately north to south. Magnetometry also reveals a large rectilinear feature, enclosing an area of approximately 50 m square with walls 3 m wide, crossing the bottom of the survey square (Figure 7). This feature further appears to connect to parts of city walls proposed by Hammer (2022) and is oriented with late ED architecture across the city (Ashby 2017). Significantly, the magnetogram confirms that this structure was impacted by, and thus predates, meander development.

4.3 | Interpreting the Lithofacies

The combined sedimentary and geomagnetic record demonstrates that the water-formed feature traversing Tell al-Hiba is the product of an uncontrolled flood rather than a purpose-built canal. First, scale: urban canals in ED Lower Mesopotamia rarely exceed 10 m in width, and even monumental city canals, such as the reconstructed GNC, are under 25 m in width. In contrast, the Lagash water-formed feature broadens to as much as 90 m and displays an arcuate planform characteristic of meander cut-offs, not engineered embankments.

Second, internal geomorphology: the magnetogram reveals scroll- and counter-point bars—sedimentary forms produced as a meander migrates, encounters bank resistance, and deposits lateral accretion sets. Such autogenic bar patterns have no documented analog in confirmed Mesopotamian canals, which typically retain linear beds with levee berms. Moreover, geomagnetic signatures of confirmed canals vary little across their length or width, having at Lagash a range of between −5 and +5 nT. By contrast, the water-formed feature exhibits a much broader and heterogeneous range, stretching between −20 and +20 nT (Figure 8). Finally, feature depth in TT1, TT2, and TT4 precludes its use as a canal engineered to accommodate boat traffic.

Third, facies architecture: all trenches intercept a gray-brown silt layer with low-angle inclined bedding. The layer thickens from ~0.2 m (TT2) to > 1 m (TT3), mirroring hydraulic-energy decay from channel thalweg to overbank margin. Proper canal fills, on the other hand, contain heterogeneous, stratified deposits: interbedded mud, sand, disarticulated shells, and cultural refuse that accumulated gradually or were transported during periodic cleaning (Geyer and Sanlaville 1996; Egberts et al. 2025). Artifact taphonomy differs as well: sherds recovered from canals are usually water-rounded and abraded by prolonged flow, whereas items entrained in a flood layer, such as the Enannatum I foundation nail and conical bowl, are carried once or covered and show little mechanical wear.

Lastly, chronostratigraphy: OSL dates from the silt's upper and lower facies (~2390 ± 220 BC) overlap the radiocarbon age of the late-ED destruction layer in Area C (~2345 BC), whereas no

FIGURE 5 | Inscribed Enannatum nail located in TT2 with findspot. The nail, dating to ca. 2425 BC, was found out of primary context within a deposit of water-laid silt.

younger material overlies the deposit. If the channel had remained an active canal, routine dredging would have introduced later artifacts and maintained navigable depth; their absence indicates rapid infill followed by abandonment.

The lithofacies described above are inconsistent with evidence for an intracity canal. The shallow depth of the water-laid deposits argues against this feature being part of an urban transportation network (e.g., Adams 1982, 134; Stone and

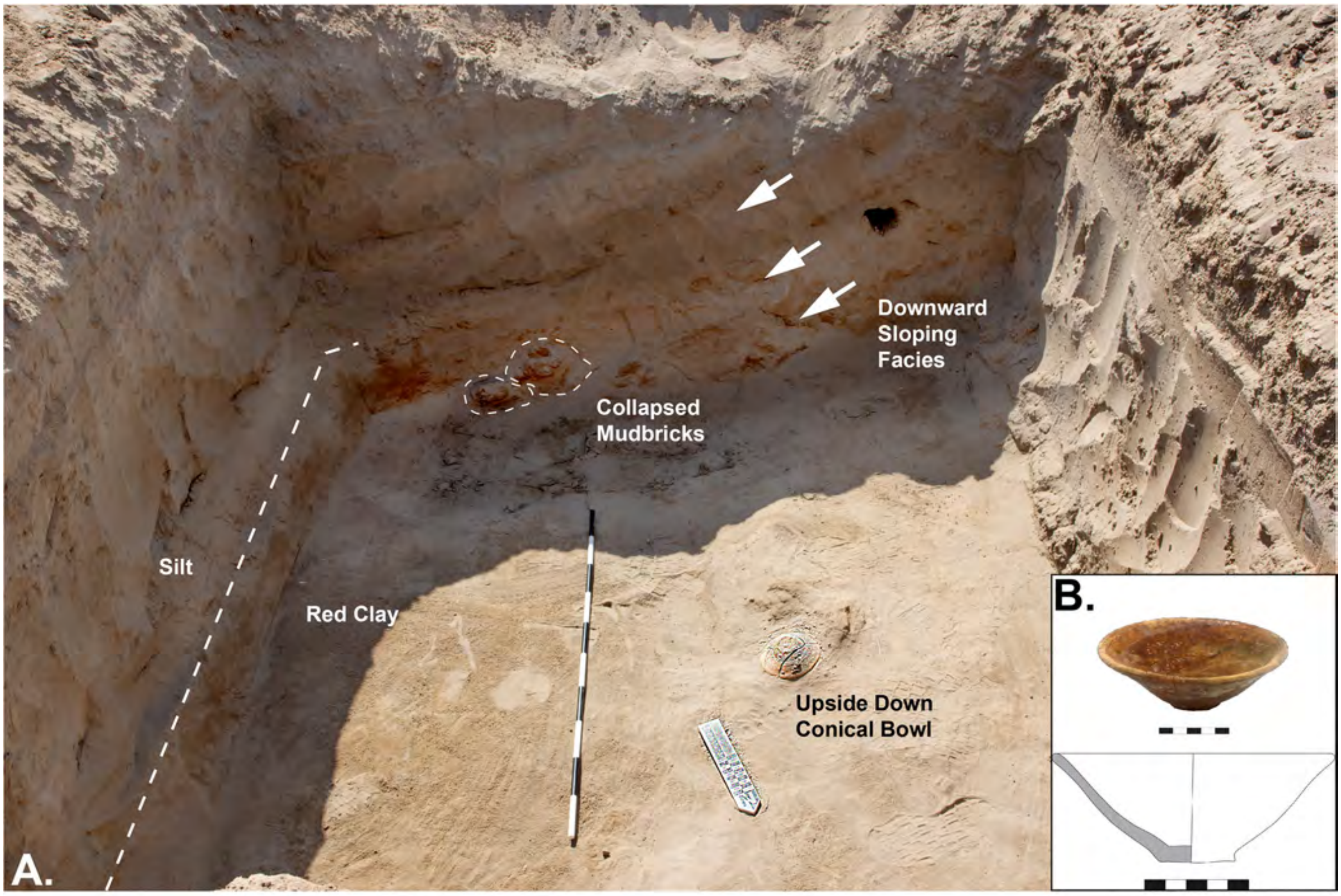

FIGURE 6 | (A) Photograph of TT3 looking west with late ED conical vessel face down on a cultural surface. Collapsed mudbricks and downward sloping facies, indicative of energetic fluvial deposition, can be seen in section (B). Inset includes photograph and drawing of conical vessel from TT3, associated with Renette (2021, 35, tab. 3.21) type HB-1a.

Zimansky 2004, 24). Instead, the geomorphological, geochronological, archeological, and ecofactual evidence strongly supports flooding associated with upstream disequilibrium in the regional river network at the close of the ED III period. This interpretation is further reinforced by findings from past excavations.

5 | Discussion

5.1 | Historical and Textual Corroboration

Historical sources confirm that Lugalzagesi sacked Lagash at the end of the ED period. Conventional dates for his reign vary based on the Middle and Low Chronologies, placing him between c. 2358–2334 BC and 2294–2270 BC, respectively (reckoning backwards from much later astral events). As mentioned in the Introduction, site survey data reflecting demographic trends strongly support this reconstruction. According to a royal inscription, Lugalzagesi's invading army devastated fortifications and hydrological infrastructure along a major state canal, bypassing Girsu and advancing toward Lagash from the northwest (Rey 2016, 65–66, fig. 26). If labor resources were already depleted due to ongoing conflicts and seasonal flooding, the impact on regional hydrology would have been severe.

The dredging and maintenance of irrigation systems were major concerns highlighted in royal inscriptions from Urukagina's early reign (Schrakamp 2018, 129). Westenholz (1977) proposed that Urukagina initially attempted to avoid conflict with Umma, suggesting that Lugalzagesi's final assault possibly occurred after a prolonged 4-year stalemate. However, considering the route and method employed in his raid, it is plausible that Lugalzagesi—formerly governor of Umma and therefore intimately familiar with Lagash's irrigation infrastructure—strategically targeted the city's most vulnerable, low-lying districts at an environmentally critical time. Carroué's textual analyses (1986, 44–46) indicate that during much of the 3rd-millennium BC, extensive wetlands surrounded Lagash on its southern, western, and eastern boundaries.

Regional DEM data emphasize the low-lying topography of the Lagash region, even following subsequent deltaic alluviation (Figure 2C). This reinforces the view that the city's immediate area, situated at the edge of the Mesopotamian steppe, lay at a lower elevation relative to much of Sumer. Given this topography, an informed invading force, such as Lugalzagesi's, likely followed the documented invasion route, deliberately sabotaging upstream hydrological infrastructure during peak flooding season. This interpretation corresponds closely with the seasonality described in the lamentation text, further substantiating the notion that the attack was carefully timed to maximize environmental and economic devastation.

TABLE 1 | Optically stimulated luminescence dates from Test Trench 1.

Sample name	Lab code	Sample depth (m)	Water content (%)[a]	In situ water content (%)	Assumed initial water content	^{238}U (ppm)[b]	^{232}Th (ppm)	K (%)	d_{cosmic} (Gy ka^{-1})[c]	Φ (μm)[d]	$d_{Natural}$ (Gy ka^{-1})	n^h	D_e (Gy)[e]	σ (%)[f]	Age (ka)[g]
TP1 T	COSL151	0.15	3	20	9	1.59 ± 0.11	4.15 ± 0.41	1.00 ± 0.04	0.22	4–15	1.97 ± 0.12	8/8	8.77 ± 0.17	0	4.45 ± 0.27
				20	9					63–125	1.78 ± 0.08	31/60	7.80 ± 0.53	26 ± 6	4.39 ± 0.36
TP1 M	COSL152	0.45	3	20		1.67 ± 0.12	4.51 ± 0.45	1.05 ± 0.04	0.19	63–125	1.84 ± 0.06	35/80	8.10 ± 0.40	20 ± 5	4.41 ± 0.29
TP1 B	COSL153	0.75	16	30	22	1.70 ± 0.12	4.55 ± 0.45	1.11 ± 0.04	0.18	4–15	1.79 ± 0.09	8/8	8.77 ± 0.16	0	4.91 ± 0.26

Note: Analytical results of OSL data reported with 1σ uncertainty. The superscript h is the number of aliquots accepted/measured.
[a]Water content expressed as mass fraction of water/wet sample assuming 5% uncertainty.
[b]Natural radioactivity measured using a high-resolution low-background gamma spectrometer.
[c]Cosmic dose rate calculated following Prescott and Hutton (1994).
[d]Particle size of quartz extractions used for equivalent dose (D_e) measurement. Note that TT1 T was measured with fine-silt and sand-sized quartz separately.
[e]Number of accepted/measured aliquots. D_e values obtained using the central age model, or weighted means of the accepted measurements.
[f]Overdispersion parameter characterizing the spreading of D_e values beyond expectation as defined by Galbraith et al. (1999).
[g]Ages reported as before 2022 CE.

5.2 | Burning and Population Decline

Koldewey's (1887) hypothesis that Lagash was a massive cemetery is demonstrably false; however, extensive evidence of burning is present across temple and royal districts, and these contexts have invariably been dated to late ED on artifactual grounds (e.g., Ashby 2017; Hansen 1978, 1987; Huh 2008). In Area C, for example, the upper building level of a late ED royal workshop (Bahrani 1989) exhibits evidence of major conflagration, as does much of the surrounding area (Carter 1989–1990). Inscriptional evidence securely dates the workshop's lower level to the reign of Enmetena (ca. 2400 BC) (Biggs 1976), while architectural and artifactual data suggest that only a few generations passed before the upper level was destroyed by intense fire, likely during a violent conflict (Bahrani 1989, 169).

Bahrani (1989) connected the discovery of sling bullets in the upper conflagration layer to an Elamite raid referenced in a letter once attributed to Enannatum II, the son of Enmetena. The letter, written by Lu'ena, a governor of Lagash's coastal district, was addressed to a temple official at Girsu and describes the interception of a looting party of 600 men returning to Elam from the city of Lagash (Bahrani 1989, 176–177). Crucially, the letter's genre suggests minimal political bias, lending credibility to its account of events. Furthermore, subsequent orthographic and prosopographic analysis has led to a reassessment of its date, now placing it at the end of Urukagina's reign—aligning it with the period following Lugalzagesi's conquest of Tell al-Hiba (Sallaberger and Schrakamp 2015, 70; see Schrakamp (in press) and Supplementary Information for an alternative reading).

As Grégoire (1962, 11) pointed out, for a war party to march into and out of Lagash undetected, the city must have already been weakened, disconnected from the central government, or largely abandoned. The letter also implies that Nigin, a city within visual range of Lagash, was similarly desolate, as no intervention was recorded. Results from excavations at Nigin likewise suggest that occupation declined at the end of the ED period (Nadali and Polcaro 2018). Moreover, the early and extensive excavations of the French at Girsu found little evidence for early and middle ED (c. 2950–2500 BC) architecture, in stark contrast to the site's later periods (Genouillac 1934, 94). Together, these data offer broad support for a significant demographic shift from south to north—downstream to upstream—after Lugalzagesi's attack.

5.3 | Chronological Correlation Between OSL and New Radiocarbon Data

The LAP recently analyzed carbonized barley seeds collected in 1970 from floor contexts in the upper and lower burn layers of Area C's royal workshop. As expected, the lower level predates the destruction layer, and both dates statistically overlap. The median value of 2345 BC for the destruction layer (Figure 9) aligns well with a putative date for Lugalzagesi's sack of the city, and we suspect this destruction rendered Lagash vulnerable to future raids.

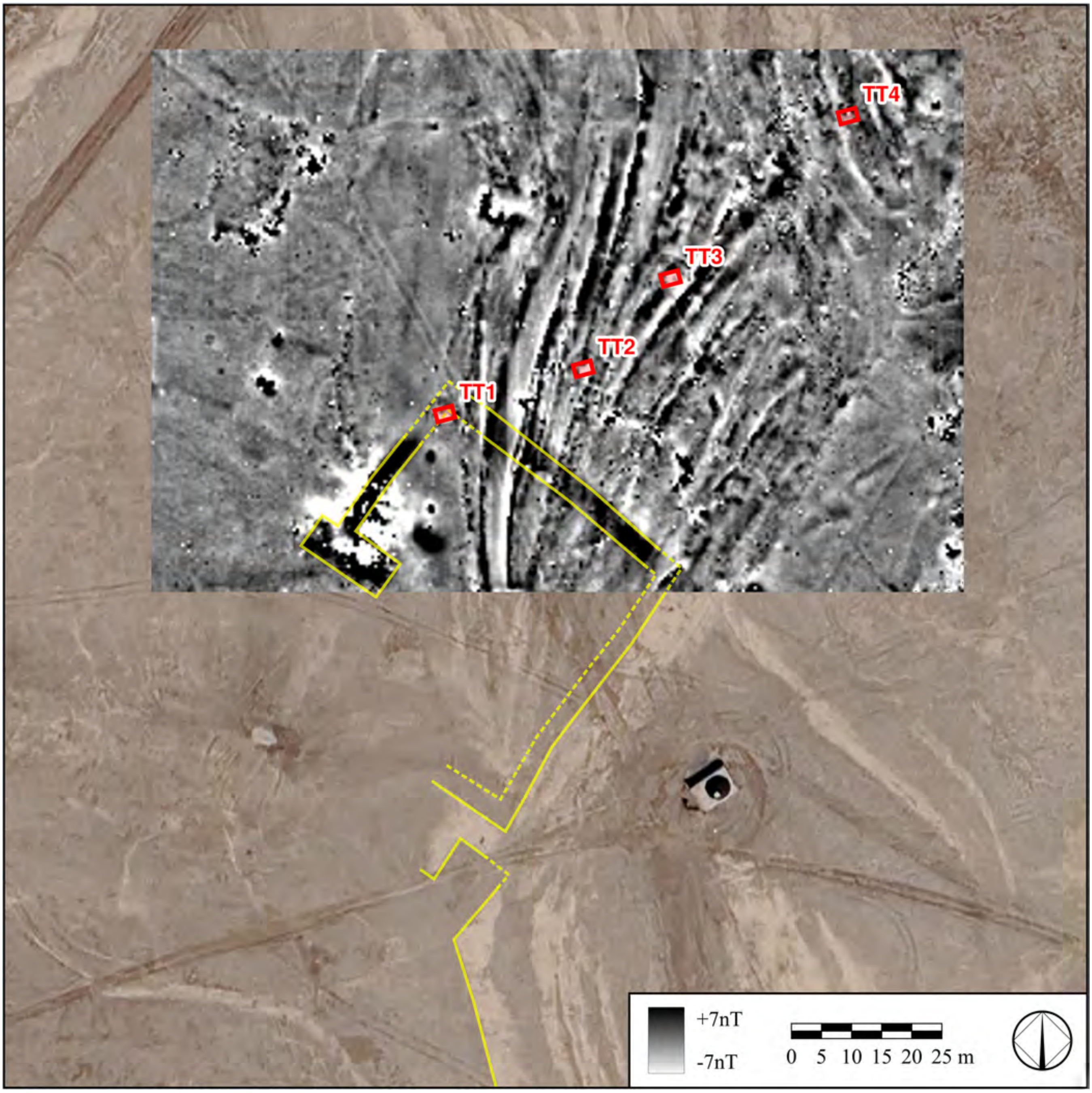

FIGURE 7 | Magnetogram overlain on satellite imagery (*Google Earth image 2024 Airbus*). Relict bars cut through a large architectural signature running northwest–southeast, outlined in yellow. Surface soil marks reveal a corner or bastion and a square structure, dating to the ED period.

A significant destruction episode was also documented during excavations in Area B, with extensive evidence of burning across the Bagara temple complex. Ashby (2017, 166) dated this destruction level and associated burning to the late ED period based on small finds and tentatively linked it to Lugalzagesi's attack, as historical texts explicitly describe him setting fire to the Bagara. Notably, no evidence for the temple's reconstruction appears until the Gudea period (ca. 2100 BC), suggesting a prolonged phase of abandonment following the destruction.

While OSL dates yield broad time ranges unsuitable for identifying discrete events, after adjusting for deflation (cf. Adams 1981, 10), the OSL chronology of the water-laid silt aligns closely with radiocarbon dates for the destruction layer in Area C (Table 1). This provides an upper chronological boundary for flooding events. Combined with test trench data that establish lower chronological bounds, the point and counterpoint bars most likely formed toward the end of the late ED period. No evidence suggests that the water-laid silt contains material postdating ED III.

5.4 | Canal, Waterway, or Flood?

The meander scroll under study is typical of laterally migrating, unconfined streams. Such morphology contrasts

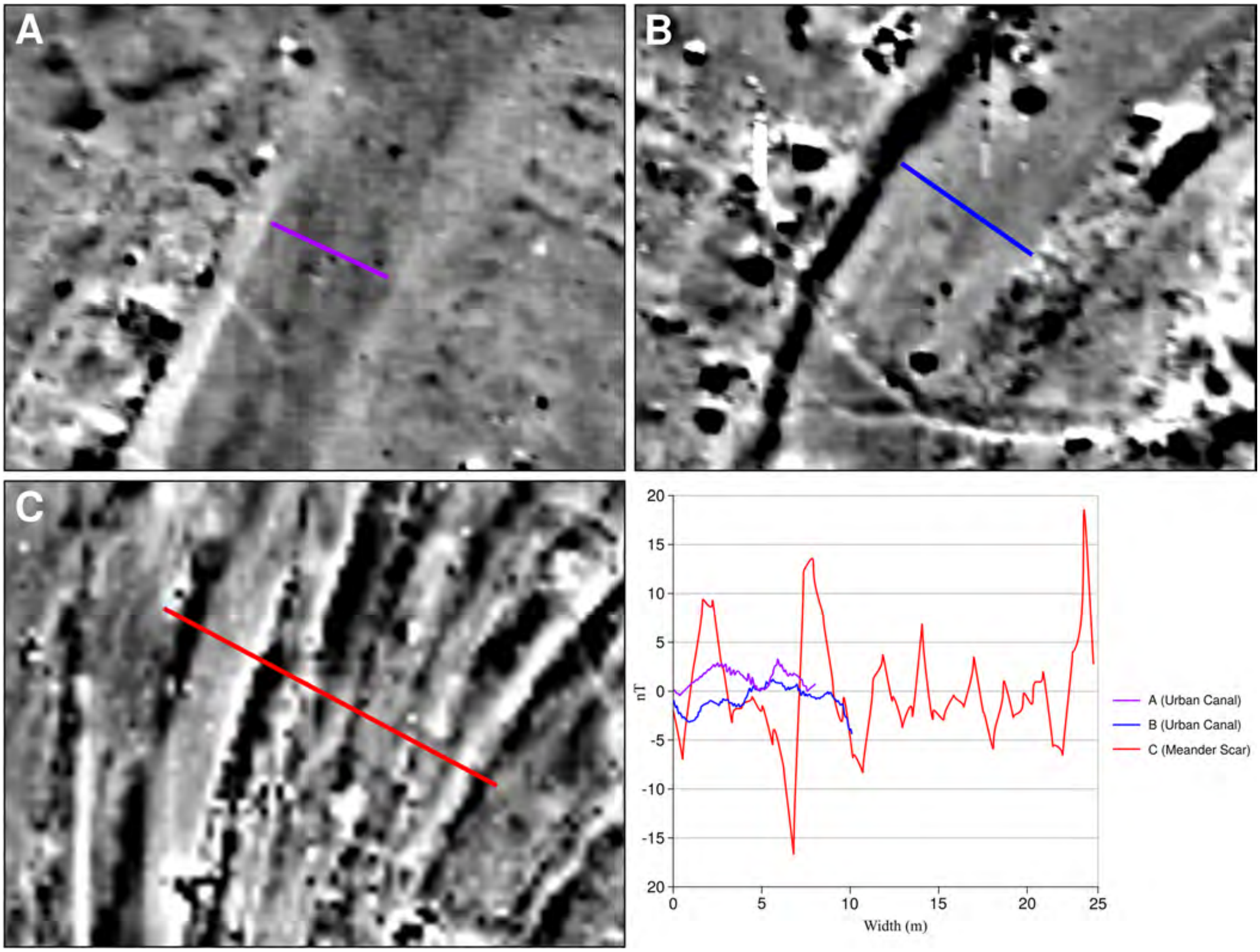

FIGURE 8 | Magnetogram details showing intensity of magnetic signal across urban canals at Lagash (A, B) and the meander scar (C).

significantly with engineered canals at Lagash and neighboring sites, which maintain consistent widths ranging from 6 to 30 m and display straight to gently curving alignments. The considerable width, pronounced sinuosity, and prominent scroll-bar formations at Lagash thus strongly indicate a non-anthropogenic origin.

Sedimentological evidence further supports this interpretation. As mentioned above, excavations of known canals at Lagash and other sites, including Girsu, Larsa, and Uruk, typically uncover stratified deposits of mud, sand, and cultural debris, accumulated incrementally and periodically disturbed, with radiocarbon dates spanning prolonged deposition periods (Geyer and Sanlaville 1996; Egberts et al. 2025). In contrast, the Lagash channel fill comprises a single, uniform layer of massive, gray-brown silt with low-angle cross-lamination, indicating rapid deposition during a singular flood event. Artifact taphonomy further corroborates this rapid deposition scenario: ceramics found in canals usually exhibit substantial rounding from prolonged transport, whereas artifacts from the Lagash silt, such as the Enannatum I foundation nail, show minimal abrasion consistent with swift burial after brief transport. Additionally, the Lagash deposit lacks internal truncations and evidence of repetitive dredging or maintenance.

Finally, the flood deposit at Lagash finds compelling parallels at other early Mesopotamian sites, indicating a broader regional pattern of catastrophic fluvial events. At Ur, for instance, C. L. Woolley documented a massive water-laid clay layer up to 3 m thick, containing few artifacts, sandwiched between Ubaid-period strata below and ED remains above, interpreting it as evidence of a significant flood (Woolley 1955). Further north at Kish, archeologists S. Langdon and L. Watelin identified multiple superimposed flood layers dating to the early third millennium BCE (Thomas 1955; Watelin 1931). One Kish flood layer marks the end of ED I (ca. 3000–2900 BC), with another, even thicker, deposit dating to ED III (around 2600 BC). Both represent abrupt inundations burying occupation levels beneath thick bands of silt. Similarly, excavations at Shuruppak (Fara) in the 1930s uncovered a destructive flood layer separating Late Protoliterate and ED I deposits (ca. 2900 BC). Not coincidentally, Shuruppak figures prominently in Mesopotamian legend as the city of the flood hero Ziusudra, illustrating how these catastrophic events embedded themselves into cultural memory.

These examples from Ur, Kish, Shuruppak, and elsewhere clearly demonstrate that episodic flooding disasters punctuated the early history of Lower Mesopotamian cities. Each site's flood layer shares key features with Lagash's deposit—a laterally extensive blanket of fine silt sharply dividing earlier and later

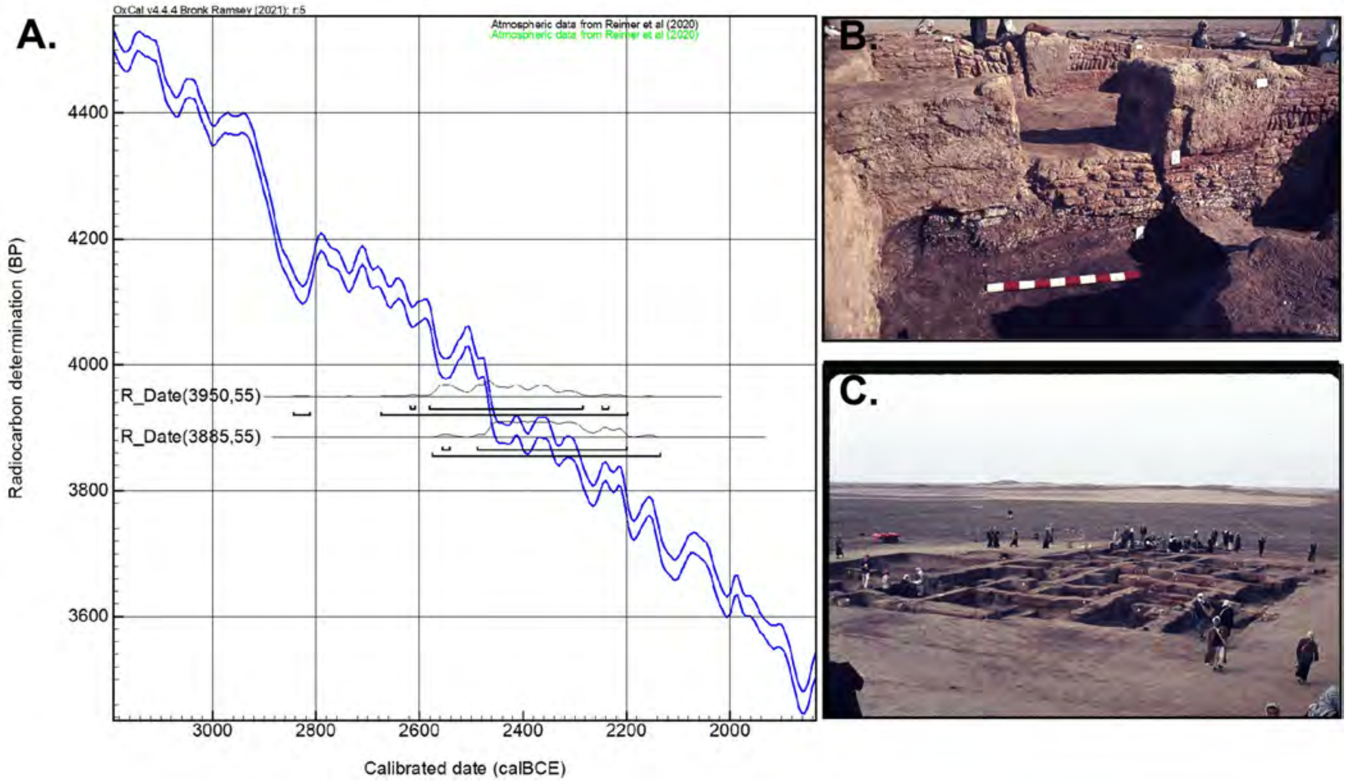

FIGURE 9 | (A) Radiocarbon dates of charred barley seeds from burned Levels I and II in Area C's administrative building. Measurements overlap with OSL dates from TT1 (also see Figure 4). (B) Well-preserved architecture in Area C building resulting from conflagration, and (C) oblique excavation view of Area C building.

habitation layers—highlighting the regional scale of such sudden hydraulic catastrophes.

6 | Conclusion

Our geoarchaeological investigation provides compelling evidence that Lugalzagesi's sack of Lagash was accompanied by a catastrophic hydrological event that reshaped the city's landscape. Stratigraphic data and OSL dating indicate that a sudden, high-energy flood inundated a core urban district during or shortly after the attack, burying architecture under > 1 m of silt. The breach likely occurred along Lagash's main canal midway between Areas B and C (Figure 2B). Notably, both Areas B and C contain conflagration layers dated to the late ED III period, reinforced by epigraphic, artifactual, and new radiocarbon evidence that tightly align with Lugalzagesi's reign. The convergence of geologic, archeological, and textual data strongly supports a scenario in which the city's hydrological infrastructure was fatally compromised during Lugalzagesi's assault, unleashing a flood that not only devastated Lagash's built environment but also hastened its demographic collapse.

The most plausible sequence is that a critical canal embankment—either deliberately breached by Lugalzagesi's forces or left untended after the invasion—failed during peak flood season, triggering widespread inundation. The timing, at the height of the spring floods, would have maximized the destructive impact: saturated levees and high river stages meant even a small breach could amplify into a torrent. In the aftermath, Lagash's low-lying districts were largely abandoned, consistent with Urukagina's unprecedented decision to relinquish the title "King of Lagash" in favor of "King of Girsu." This shift implies a strategic relocation of political authority and population upstream, into areas spared from flooding. Textual records from a generation later underscore the fallout: the Lu'ena letter portrays Lagash and nearby Nigin as desolate, unable to muster resistance to an Elamite raid. Compounding the trauma, environmental data point to worsening soil salinity in Lagash's fields at the end of the 3rd-millennium BC, further undermining agricultural recovery (Jacobsen and Adams 1958; Civil 1987; Sallaberger 1999, 175–177). In short, the breach of Lagash's canal system turned a military conquest into an ecological collapse—one from which the city never fully recovered.

More broadly, our findings highlight the dual role of water infrastructure in ancient Mesopotamian urbanism as both a foundation for prosperity and a latent liability during conflict. Irrigation networks and canals were the lifelines of 3rd-millennium cities, but their tight integration into the urban fabric created single points of failure that could be exploited by enemies. Hydraulic fragility was an inherent risk of Sumerian cities' entropic growth (Algaze 2018). When one component of a finely tuned water-control system failed, the effects cascaded: flooding, erosion, agricultural collapse, famine, and displacement. The result was not only immediate destruction but also long-term demographic and environmental shifts, as survivors regrouped on higher ground and formerly productive farmland reverted to marsh. The interdependence of early cities and their engineered waterscapes meant that warfare could have truly civilizational consequences, abruptly reversing generations of landscape modification and labor investment.

Crucially, the conquest of Lagash appears to mark one of the earliest documented instances of weaponizing water in interstate warfare. Lugalzagesi's tactics foreshadow a broader strategic shift wherein military campaigns targeted ecological infrastructure. Within a century, Naram-Sin of Akkad (c. 2250 BC) is recorded using similar methods, and by the early second millennium BC such practices had become common in Mesopotamia (Foster 2016; Schrakamp 2018, 125, ft. 37). The Lagash flood thus stands as an archeological precedent for later episodes of hydraulic warfare attested in both texts and the archeological record. For example, in 689 BC, the Assyrian king Sennacherib notoriously destroyed Babylon by damming the Euphrates and diverting its waters over the city's ruins. During China's Warring States period, besiegers at the Battle of Jinyang (453 BC) diverted the Fen River to inundate the city, until the desperate defenders retaliated by breaking the dikes and drowning the invaders' camp (Tse 2023). Over a millennium later, Genghis Khan's Mongol armies in 1221 AD annihilated the Khwarazmian capital of Gurganj by demolishing the Oxus River embankments and flooding the entire city (Saunders 1971). Each of these cases demonstrates the devastating efficacy—and lasting consequences—of turning water management systems into weapons of war. The destruction of canals, dikes, or dams could swiftly decide a siege or punish a rebelling populace, but it also tended to erase infrastructure that had sustained those urban economies for centuries.

In this light, the tragedy of Lagash may represent the earliest known record of deliberate hydraulic warfare. What unfolded at Lagash circa 2350 BC was not an isolated catastrophe, but rather an event at the tipping point of Mesopotamian political evolution, when inter-polity rivalries were intensifying and rulers began to realize that the control of water could be as strategically important as the control of armies. Lugalzagesi's onslaught, coming at the end of the ED period, heralded a new paradigm in which conquering an enemy's water infrastructure yielded enduring results. The fact that Lagash never regained its prominence after this episode underscores how profoundly environmental factors intertwined with human conflict to shape history. Ultimately, by integrating geoarchaeology, textual analysis and geophysics, this study sheds new light on the intersection of warfare, water management, and urban resilience in the ancient world, offering broader insights into the environmental dimensions of conflict in early state societies.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.
Figure 1: Western section of Test Trench 1, including an upper water lain level and a lower anthropogenic level. **Figure 2:** Northern section of Test Trench 2. Note the shallow depth of silt facies. **Figure 3:** Eastern section of Test Trench 3. **Figure 4:** Western section of Test Trench 4.