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Formation-Scale Lithostratigraphic Subdivision of the Nubian Sandstone Succession Along the Quseir–Qift Road, Eastern Desert, Egypt

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Abstract

The Nubian Sandstone succession exposed along the Quseir–Qift Road, Eastern Desert, Egypt, has commonly been treated as a broad sandstone-dominated interval, limiting local stratigraphic resolution. This study establishes a formation-scale lithostratigraphic subdivision of that succession. Field control comprises 18 Global Positioning System (GPS)-referenced localities—15 within the Quseir–Qift corridor and three comparison localities at Wadi Hammamat. Principal measured-section controls, contact localities, and lateral checks were organized into eight composite logs within a 1:25,000 mapping framework. From base to top, the succession comprises the Araba, Abu Thora, Abu Durba, Malha, Bahariya, and Taref formations, with recorded thicknesses of 77.5–84.5 m, 68–72 m, approximately 24 m, approximately 78 m, 37–60 m, and 7–37 m, respectively. Formation boundaries were distinguished from ordinary facies changes by persistent package-scale shifts in lithological association and vertical organization, reproducible stratigraphic position, and traceable contact or marker relationships where exposure allowed. Regional correlation was evaluated only after local differentiation. The observed facies associations are consistent mainly with fluvial systems, with local tidal or shallow-water influence in Araba and Abu Thora and a restricted evaporitic setting in Abu Durba. Because no independent local biostratigraphic or geochronologic ages were obtained, formation ages remain regional, correlation-based assignments and may be diachronous. The framework improves local stratigraphic resolution without proposing new formal units or a definitive regional solution for the Nubian Sandstone.

Keywords: Nubian Sandstone succession; lithostratigraphy; formation-scale subdivision; Quseir–Qift Road; Eastern Desert; stratigraphic correlation; mappable formations; Egypt

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1. Introduction

The Nubian Sandstone succession is one of the most widely used but stratigraphically debated siliciclastic successions in Egypt and adjacent parts of northeast Africa. Since the early use of the term by Russegger [1], it has been applied to extensive sandstone-dominated successions that commonly show broad lithological similarity and limited age-diagnostic fossil content. Subsequent workers used the term as a formation, series,

lithofacies, rock type, or broader stratigraphic complex and assigned different age ranges in different regions. This variable usage has made Nubian Sandstone a useful regional field term but has also generated persistent problems in lithostratigraphic nomenclature, age interpretation, and local correlation.

Previous work provides several kinds of context rather than a single directly comparable local scheme. Quseir-area studies supplied stratigraphic descriptions, geological relationships, and broader Upper Cretaceous context [2–7], while more recent studies addressed fluvial architecture and vertebrate footprints within Nubian Sandstone successions of the Eastern Desert [8,9]. Regional schemes elsewhere in Egypt and northeast Africa demonstrate that the historical Nubian Sandstone concept may encompass multiple lithostratigraphic units [10–19]. Table 1 therefore compares the earlier products most relevant to the Quseir–Qift stratigraphic problem with the field evidence added by the present study, rather than treating distant regional schemes as local precedents.

Table 1. Direct comparison between selected previous interpretations relevant to the Quseir–Qift–Gebel Duwi area and the present local field framework.

Source	Geographic/Analytical Emphasis	Contribution Relevant to the Local Problem	Relation to the Present Framework
Youssef [2,3]	Quseir area; stratigraphic studies and Upper Cretaceous relationships	Established an early local stratigraphic framework for the Quseir area.	Provides local historical context; the present study adds GPS-referenced boundary control and a six-formation field subdivision of the Nubian Sandstone interval.
Said [5]; Issawi [6]	Egypt-wide and central–southern Egypt syntheses	Provided regional stratigraphic and chronostratigraphic context for Nubian Sandstone and younger Cretaceous successions.	Regional syntheses guide comparison, but local units here are differentiated from field evidence before regional age assignment.
Ward and McDonald [7]	Central Eastern Desert; Nubia Formation subdivisions and depositional setting	Demonstrated important internal subdivision and sedimentological organization within the Nubia Formation.	An important local precedent; the present study tests six established formation names against measured vertical successions, explicit contacts, and two-traverse boundary relationships along the Quseir–Qift corridor.
Abdel-Fattah [8]	Central Eastern Desert; Upper Cretaceous Nubia fluvial architecture	Documented high-resolution sedimentary architecture and fluvial organization.	Provides sedimentological context; the present contribution is a formation-scale lithostratigraphic framework for the broader exposed succession.

Table 1. *Cont.*

Source	Geographic/Analytical Emphasis	Contribution Relevant to the Local Problem	Relation to the Present Framework
Kassab et al. [9]	Southern Eastern Desert; pre-Campanian Nubian Sandstone footprints	Added palaeontological/ichnological evidence from Nubian Sandstone strata.	Biogenic observations are used here only as supporting evidence tied to field-defined units and are not treated as independent age markers.
EGSMA Quseir sheet [20]	Regional geological mapping at 1:250,000	Provides the regional geological base and distribution of major rock units.	The present 1:25,000 field framework adds 15 corridor GPS controls and formation-contact interpretation; the restricted Abu Durba interval is resolved in logs and field observations rather than as a separate map polygon at this scale.
Present study	Quseir–Qift corridor; 18 localities and eight composite logs	Integrates measured vertical successions, formation contacts, lateral field controls, and regional comparison.	Recognizes six established formation names locally; it proposes neither new formal units nor independent local chronostratigraphic ages.

Note. The comparison is deliberately product- and scale-based. It does not imply that earlier studies lacked stratigraphic value or that the six formation names are new. The distinction tested here is the integrated local use of measured vertical successions, GPS-referenced contact controls, and field-traced package boundaries along the Quseir–Qift corridor. Regional age assignments are evaluated separately in Section 5.2.

The literature reviewed for this study does not document the same integrated corridor-scale framework in which six established Egyptian formations are differentiated using measured vertical successions, GPS-referenced boundary controls, and field-traced package relationships. The contribution is therefore delimited to a local application and test of established formation names along the Quseir–Qift corridor; it is not a proposal of new formal nomenclature and not a claim of priority outside this study area.

The succession is differentiated locally before any regional correlation is attempted. Local recognition relies on stratigraphic position, persistent lithological associations, vertical stacking, measured thickness, and contact relationships. Sedimentary structures and fossil or trace-fossil observations provide supporting evidence that is tied to particular exposures. Regional comparison is then used to evaluate compatibility with established formation names, not as a circular criterion for defining the local units.

Accordingly, this paper aims to document the formation-scale lithostratigraphic framework of the Nubian Sandstone succession along the Quseir–Qift Road, define the operational field criteria that separate formation boundaries from internal facies changes, evaluate lateral continuity and alternative boundary relationships, assess regional correlations and their uncertainty, and summarize only those depositional implications supported by the observed facies associations.

2. Geological Setting

The study area lies along the Quseir–Qift Road in the Central Eastern Desert of Egypt, west of Quseir and near Gebel Duwi. The 15 field localities within the mapped corridor

span 26°06′50″–26°08′29.7″ N and 34°00′21.9″–34°03′15.51″ E; three comparison localities at Wadi Hammamat lie outside the detailed map. The regional geological framework is represented on the 1:250,000 EGSMA Quseir sheet [20], whereas the present formation-contact interpretation is compiled at 1:25,000.

The exposed Phanerozoic cover rests on the Neoproterozoic crystalline basement of the Arabian–Nubian Shield [21–23]. In the Quseir–Gebel Duwi area, the sedimentary cover occurs as discontinuous outliers in which the Nubian Sandstone succession occupies the lower part and is overlain by younger Upper Cretaceous strata, including the Quseir and Duwi formations where preserved [2–7,20].

Previous local and regional work established the broad basement–Nubian Sandstone–Upper Cretaceous stratigraphic arrangement but used different levels of subdivision and map resolution (Table 1). The present problem is therefore not the existence of a Nubian Sandstone interval, but whether its discontinuous exposures along the road can be separated reproducibly into formation-scale packages using contacts and repeated vertical successions.

Along the Quseir–Qift Road, the outcrop is structurally and topographically dissected, and some intervals are laterally restricted or locally absent. Consequently, a single vertical section is insufficient to establish the framework: formation recognition requires repeated section controls, boundary observations, and lateral checks across separate exposure windows. This discontinuous exposure also defines an important limitation on how confidently individual contacts can be extended between field controls.

3. Materials and Methods

Field data were collected during two seven-day geological campaigns in February 2022 and February 2023. Eighteen field localities were recorded with a Garmin eTrex H Global Positioning System receiver (Garmin International, Inc., Olathe, KS, USA); the receiver-displayed positional accuracy was ±3 m at all recorded localities. Fifteen localities lie within the Quseir–Qift corridor and three Wadi Hammamat localities were used only to compare basal Araba exposures. The localities are not equivalent complete sections: they comprise principal measured-section controls, formation-contact controls, internal stratigraphic observations, and comparison sites. Supplementary Table S1 lists the exact WGS 84 coordinates, field role, composite-log association, and boundary/lateral-continuity contribution of every site.

The regional geological framework was taken from the 1:250,000 Quseir sheet of the Egyptian Geological Survey and Mining Authority (EGSMA) [20]. Coordinates reported by Khozyem et al. [24] were used only to delimit the geographic extent of the detailed map; lithostratigraphic boundaries were not adopted from that study. EGSMA data and field observations were integrated in ArcGIS 10.5 (Esri, Redlands, CA, USA) using WGS 1984/UTM Zone 36N (EPSG:32636), and the detailed map was compiled at 1:25,000. Geological units outside the scope of this study were retained from the EGSMA base map. The restricted Abu Durba interval is not represented as a separate polygon in Figure 1B at this scale; its presence and absence are resolved from the section, contact, and log data.

Coordinates were collected at exposed formation contacts and diagnostic stratigraphic positions at variable spacing. Contact segments were extended between field controls only where the same package-scale lithological break, marker interval, and stratigraphic relationship could be followed. Where exposure was interrupted, map traces represent interpolation between bracketing controls rather than continuous exposure, and contacts were not projected across gaps for which the field relationship could not be checked. Google Earth imagery was used as a supporting visual check of waypoint positions and exposed contact traces and to identify plotting or transcription discrepancies against field notes; it

was not used as the primary basis for formation identification. Contact traces were initially joined between field controls in Google Earth and transferred to the final GIS framework.

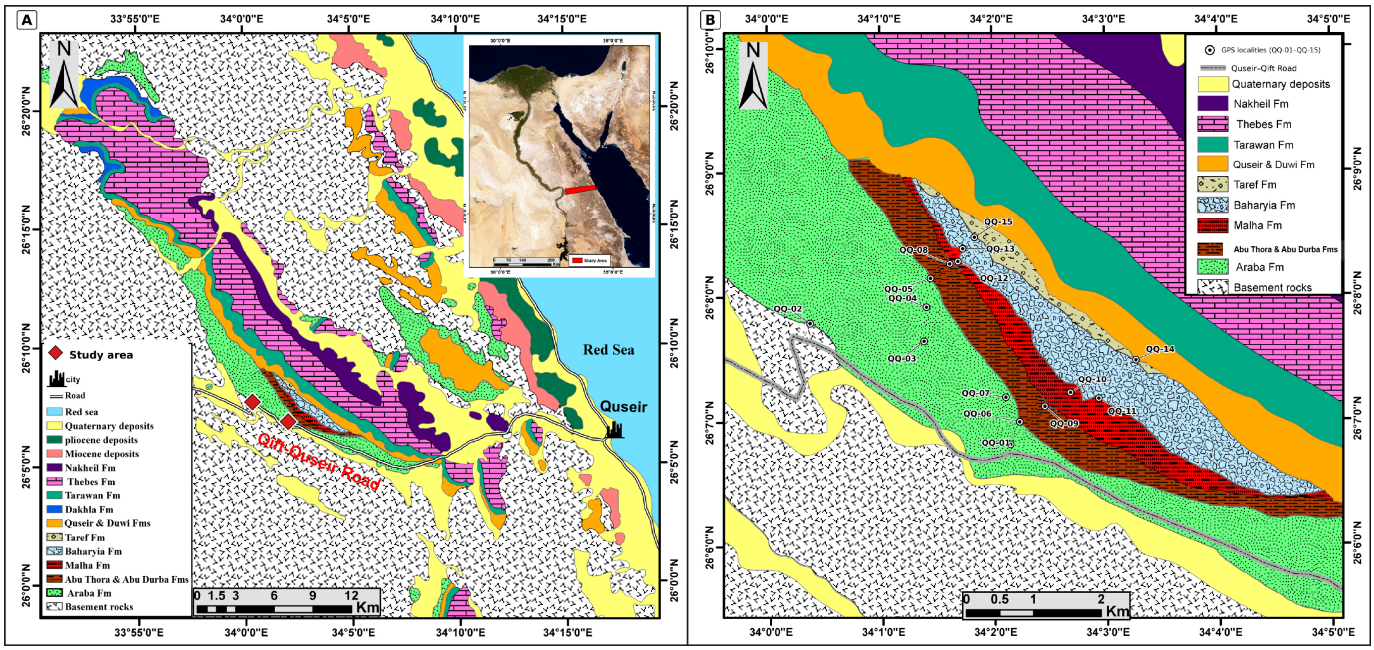

Figure 1. Location and geological setting of the Quseir–Qift Road study area, Central Eastern Desert, Egypt. (**A**) Regional geological framework compiled from the EGSMA Quseir map [20]; coordinates from Khozyem et al. [24] were used only to delimit the detailed-map extent. (**B**) Detailed map showing the mapped formation units and 15 GPS field localities (QQ-01–QQ-15), cross-referenced to Supplementary Table S1. At this map scale, the restricted Abu Durba occurrence is shown together with Abu Thora in the legend; Abu Durba is resolved separately in the measured/logged succession and field-contact data. The three Wadi Hammamat comparison localities (WH-01–WH-03) lie outside this panel. Google Earth imagery was used only as a supporting visual check of waypoint and contact positions.

An observed lithological change was treated as a formation boundary only when it marked a persistent package-scale change in lithological association or vertical organization, occupied a consistent stratigraphic position relative to adjacent packages, and could be tied to a reproducible contact or marker relationship where exposure allowed. Isolated changes in colour, grain size, bed thickness, or a single lens that could not be followed beyond one exposure were treated as internal facies variation rather than formation boundaries. Diagnostic boundary evidence includes the basement nonconformity and basal conglomerate of Araba, the transition to the finer heterolithic Abu Thora package, the restricted claystone–dolostone–gypsum association of Abu Durba, the erosional basal conglomerate of Malha, and the coarser basal lag at the Bahariya–Taref boundary.

The eight composite logs were assembled from principal measured-section controls rather than by averaging or mathematically reducing all 18 localities. The two Araba logs are anchored by QQ-01 and QQ-02; the Abu Thora logs by the QQ-07 traverse and the QQ-05–QQ-08 traverse, with QQ-09 documenting the restricted Abu Thora–Abu Durba boundary; the Malha logs by QQ-10–QQ-11 and QQ-08–QQ-12; and the two Bahariya–Taref logs by the paired section controls QQ-11/QQ-14 and QQ-12/QQ-15, with QQ-13 providing an internal Bahariya control. Other sites supplied supplementary contact or lateral-continuity checks, while WH-01–WH-03 were comparison sites and were not used to construct the eight corridor logs. At each traverse, logging proceeded upward from the oldest exposed unit, formation bases served as local datums, and observations from

separate exposure windows were combined only when marker-bed continuity and contact relationships established lateral equivalence. Bed thickness was measured with a tape perpendicular to bedding; rare covered intervals were shallowly cleared at their lower and upper boundaries before measurement.

Local formation recognition was completed before comparison with formations outside the study area. Regional names and ages were evaluated from published lithostratigraphic relationships only after the local packages had been differentiated. No independent local index-fossil, radiometric, or other geochronologic dating was undertaken, and morphology-based trace labels were not used as age markers. Consequently, correlation confidence is reported separately from local field recognition in Section 5.2 and Table 3.

4. Results: Lithostratigraphic Subdivision

Field mapping and eight composite logs distinguish six formations, from base to top: Araba, Abu Thora, Abu Durba, Malha, Bahariya, and Taref (Table 2). The local units are defined as formation-scale packages rather than collections of individual facies: diagnostic boundaries require persistent changes in lithological association and vertical organization at reproducible stratigraphic positions, whereas bed-scale changes that lack lateral or stratigraphic persistence remain internal facies variation. Regional correlation is evaluated separately in Section 5.2. Observations vary among exposures, so non-ubiquitous features are tied to specific logs, site controls, or illustrated localities (Supplementary Table S1).

4.1. Araba Formation

The Araba Formation was introduced for the Cambrian siliciclastic succession of southern Sinai [25,26]. Subsequent regional work has documented its lithostratigraphic position and facies in Sinai and the Eastern Desert [27,28]. Along the Quseir–Qift Road, the name is applied to the basal sandstone-dominated unit above the crystalline basement. The assignment is based locally on this basal position, the basal conglomerate and pebbly sandstone, and the formation's vertical succession; regional comparison is discussed separately in Section 5.

The two Araba composite logs, anchored by the principal section controls QQ-01 and QQ-02, are 84.5 and 77.5 m thick, respectively; QQ-03 and QQ-04 provide supplementary upper/internal Araba control, and QQ-05 marks the upper Araba–Abu Thora boundary (Supplementary Table S1). The basal conglomeratic interval is approximately 1.5 m thick (Figure 2A,B).

The lower contact is a sharp erosional nonconformity above the Precambrian crystalline basement (Figure 3A,B). Basal conglomerate and pebbly to coarse-grained sandstone directly overlie the irregular basement surface and provide the principal field criterion for locating the formation base (Figure 3C,D).

Above the basal conglomerate, the formation comprises pebbly to coarse-grained sandstone with subordinate siltstone and shale- or paleosol-like horizons. Planar and trough cross-bedding, herringbone cross-bedding, ripple marks, hummocky cross-stratification, scours, and pebbly lenses occur in the illustrated sections (Figures 2 and 3).

The coarse lower succession and its upward transition into finer intervals distinguish the Araba Formation from the more heterolithic Abu Thora Formation.

Bilobed surface traces and vertical burrows in the upper Araba sandstone are described here as Cruziana-like and Skolithos-like morphologies (Figure 4A–C). These are morphology-based field assignments rather than formal ichnotaxonomic determinations and are not used independently for age assignment.

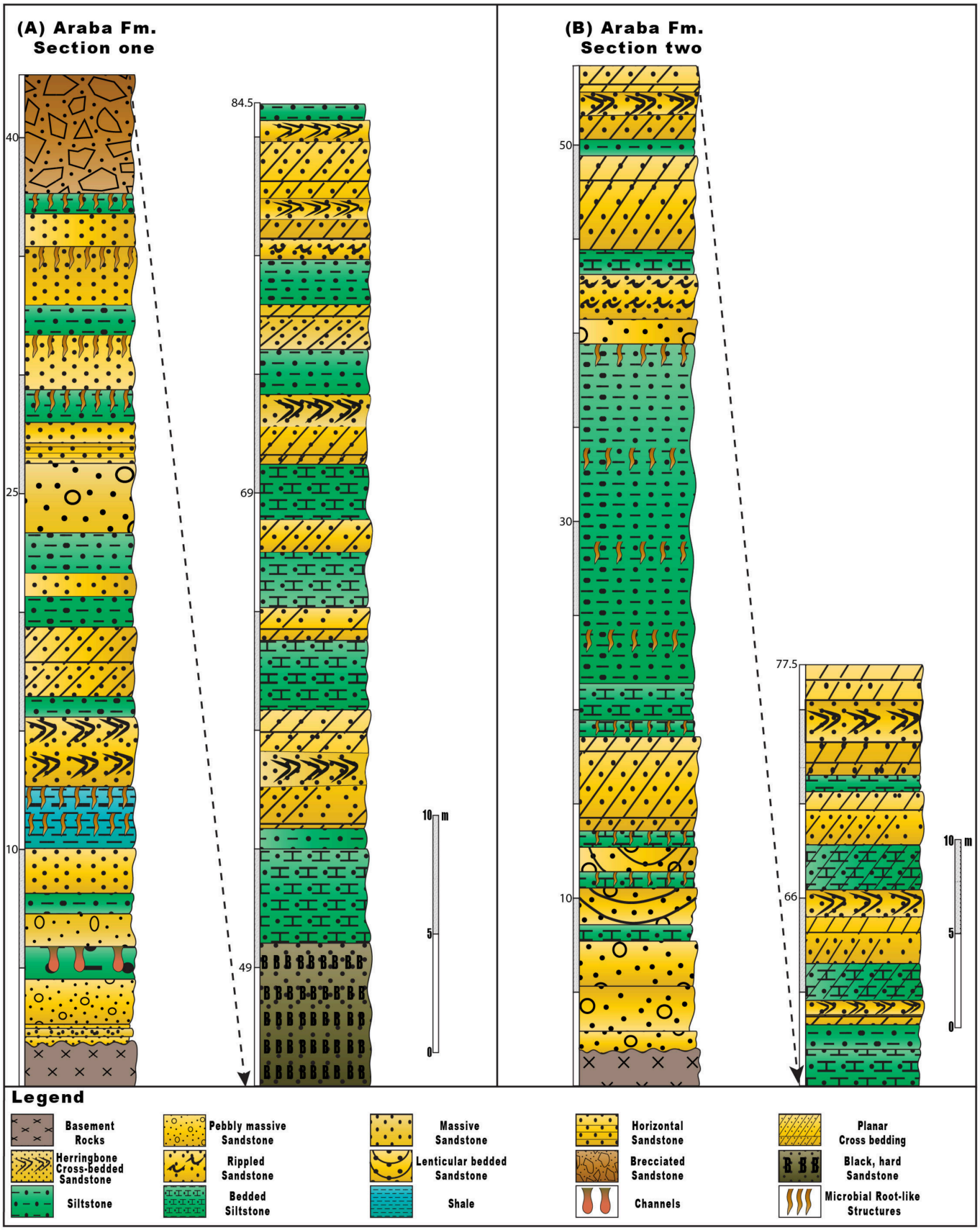

Figure 2. Composite logs of the Araba Formation: (**A**) 84.5 m and (**B**) 77.5 m. The logs show the basal relationship above basement and the formation's representative vertical organization.

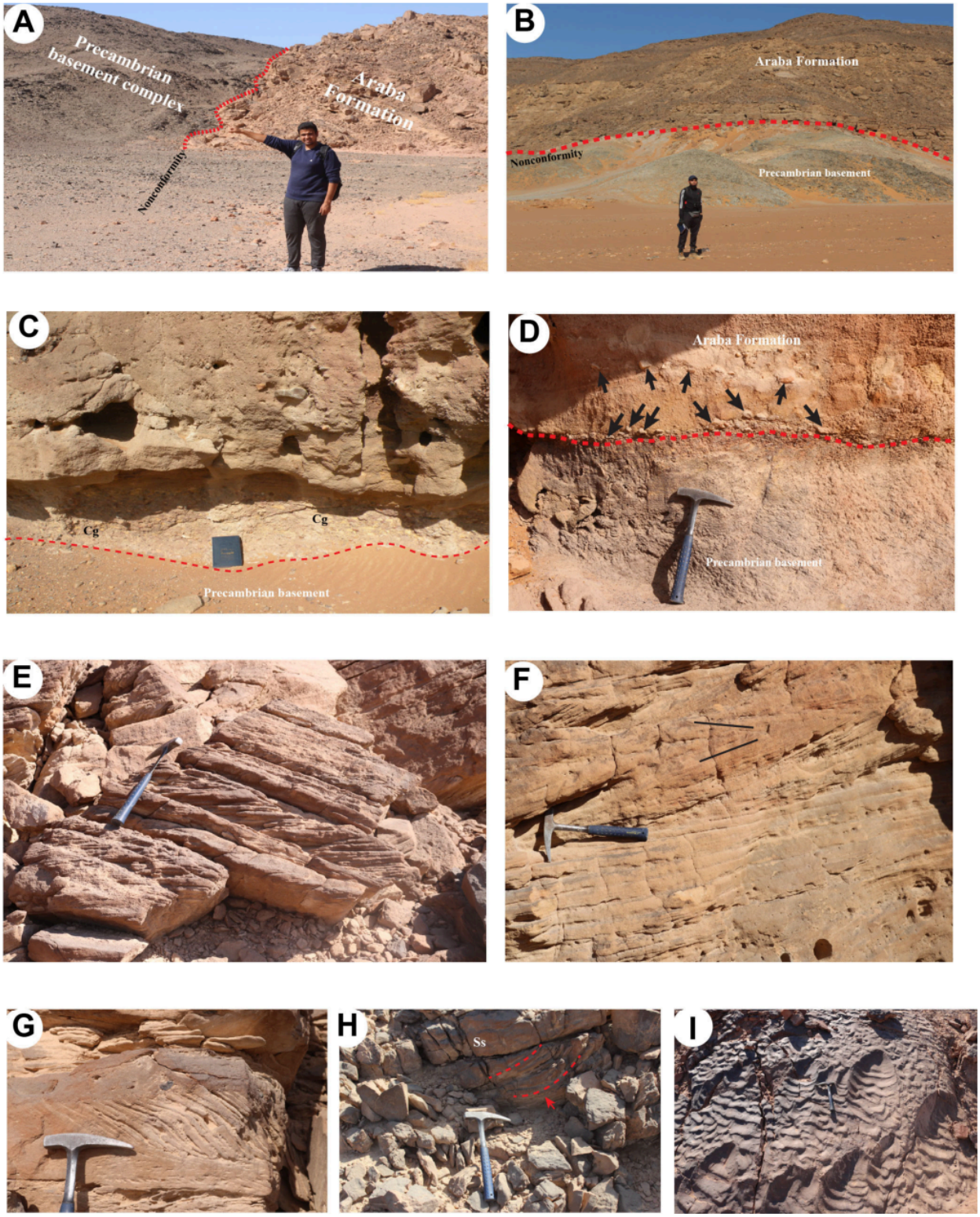

Figure 3. Field photographs of the Araba Formation. (**A**) Basal nonconformity above Precambrian basement. (**B**) Pebbly sandstone of the Araba Formation above weathered Precambrian basement at Wadi Hammamat. (**C**) Approximately 1.5 m of basal conglomerate (Cg) overlain by pebbly sandstone. (**D**) Conglomerate with rounded quartzite, granite, and chert clasts. (**E**) Planar cross-bedded pebbly sandstone. (**F**) Herringbone cross-bedding. (**G**) Hummocky cross-stratification. (**H**) Trough cross-bedding in sandstone (Ss). (**I**) Asymmetrical ripple marks.

Table 2. Lithostratigraphic framework of the locally recognized Nubian Sandstone formations along the Quseir–Qift Road.

Formation	Stratigraphic Position	Main Lithology	Thickness	Lower Contact	Upper Contact	Diagnostic Separation from Adjacent Units
Araba Formation	Lowermost locally recognized unit; overlies the Precambrian basement and underlies the Abu Thora Formation	Basal conglomerate, pebbly sandstone, medium- to coarse-grained sandstone, siltstone, and shale/paleosol-like horizons	84.5 m and 77.5 m in the studied composite logs; basal conglomerate ≈ 1.5 m	Sharp erosional nonconformity above Precambrian crystalline basement	Sharp, mappable lithological transition; no erosional lag or relief observed at the illustrated contact (apparently conformable)	Basement nonconformity plus basal conglomerate/pebbly sandstone distinguish the base; upward change to finer, more heterolithic strata separates Araba from Abu Thora.
Abu Thora Formation	Overlies the Araba Formation; underlies the Abu Durba Formation, where it is preserved; or the Malha Formation, where Abu Durba is absent	Fine- to medium-grained sandstone, siltstone, heterolithic sandstone–siltstone intervals, paleosol-bearing horizons, and ferruginous/Mn-rich intervals	68–72 m in the studied composite logs	Sharp, mappable lithological transition above Araba; apparently conformable at the illustrated contact	Abu Durba where it is preserved; the erosional Malha base, where Abu Durba is absent	Finer heterolithic sandstone–siltstone architecture with paleosol-bearing and ferruginous/Mn-rich intervals contrasts with coarser Araba below; the absence of the dolostone–gypsum association distinguishes it from Abu Durba, and the Malha basal erosional surface separates it where Abu Durba is absent.
Abu Durba Formation	Locally preserved between the Abu Thora and Malha formations	Paleosol-rich claystone, ferruginous sandstone, dolostone, gypsum, and stromatolitic dolostone	Approximately 24 m in the available composite log	Sharp lithological boundary above Abu Thora	Sharp erosional unconformity below Malha	The restricted claystone–dolostone–gypsum package with stromatolitic dolostone lies between the siliciclastic Abu Thora below and the basal-conglomeratic Malha above; its local absence is itself a mapped/section relationship.
Malha Formation	Overlies the Abu Durba Formation, where it is preserved, or the Abu Thora Formation, where Abu Durba is absent; underlies the Bahariya Formation	Sandstone, siltstone, claystone, basal conglomeratic interval, and terminal ferruginous sandstone; informal lower and upper intervals	Approximately 78 m in the studied composite logs	Major erosional unconformity above Abu Durba, where it is preserved, or directly above Abu Thora, where Abu Durba is absent	Sharp, non-erosional lithostratigraphic contact with Bahariya	Erosional basal conglomerate and overlying sandstone–siltstone–claystone packages distinguish Malha from older units; the terminal ferruginous sandstone is followed by the finer cyclic Bahariya succession.

Table 2. *Cont.*

Formation	Stratigraphic Position	Main Lithology	Thickness	Lower Contact	Upper Contact	Diagnostic Separation from Adjacent Units
Bahariya Formation	Overlies the Malha Formation and underlies the Taref Formation	Fine- to medium-grained sandstone, siltstone, claystone, ferruginous bands/crusts, and paleosol-bearing intervals	37 m and 60 m in the studied composite logs	Sharp, non-erosional lithostratigraphic contact above Malha	Sharp erosional contact with Taref	Cyclic fine-grained ferruginous sandstone–siltstone–claystone and paleosol-bearing intervals contrast with Malha below and are truncated by the coarser basal lag/pebbly sandstone of Taref above.
Taref Formation	Uppermost locally recognized Nubian Sandstone unit; overlies the Bahariya Formation and underlies the Quseir Formation	Ferruginous quartzose and pebbly sandstone with subordinate siltstone and shale; local greenish-gray siltstone upward	7 m and 37 m in the studied composite logs	Sharp erosional contact above Bahariya	Sharp lithostratigraphic contact with the Quseir Formation	Basal erosional lag and ferruginous/pebbly sandstone distinguish Taref from finer cyclic Bahariya below; the upper boundary is marked by a shift to finer Quseir siltstone and shale.

Note. Thicknesses, contacts, and lithological descriptions are based on the present field mapping and composite logs. The last column emphasizes package-scale features used to separate each unit from its neighbours; individual bed-scale facies changes were not treated as formation boundaries. Chronostratigraphic ages cited for correlated formations are literature-based regional assignments, not independent ages obtained from the Quseir–Qift succession.

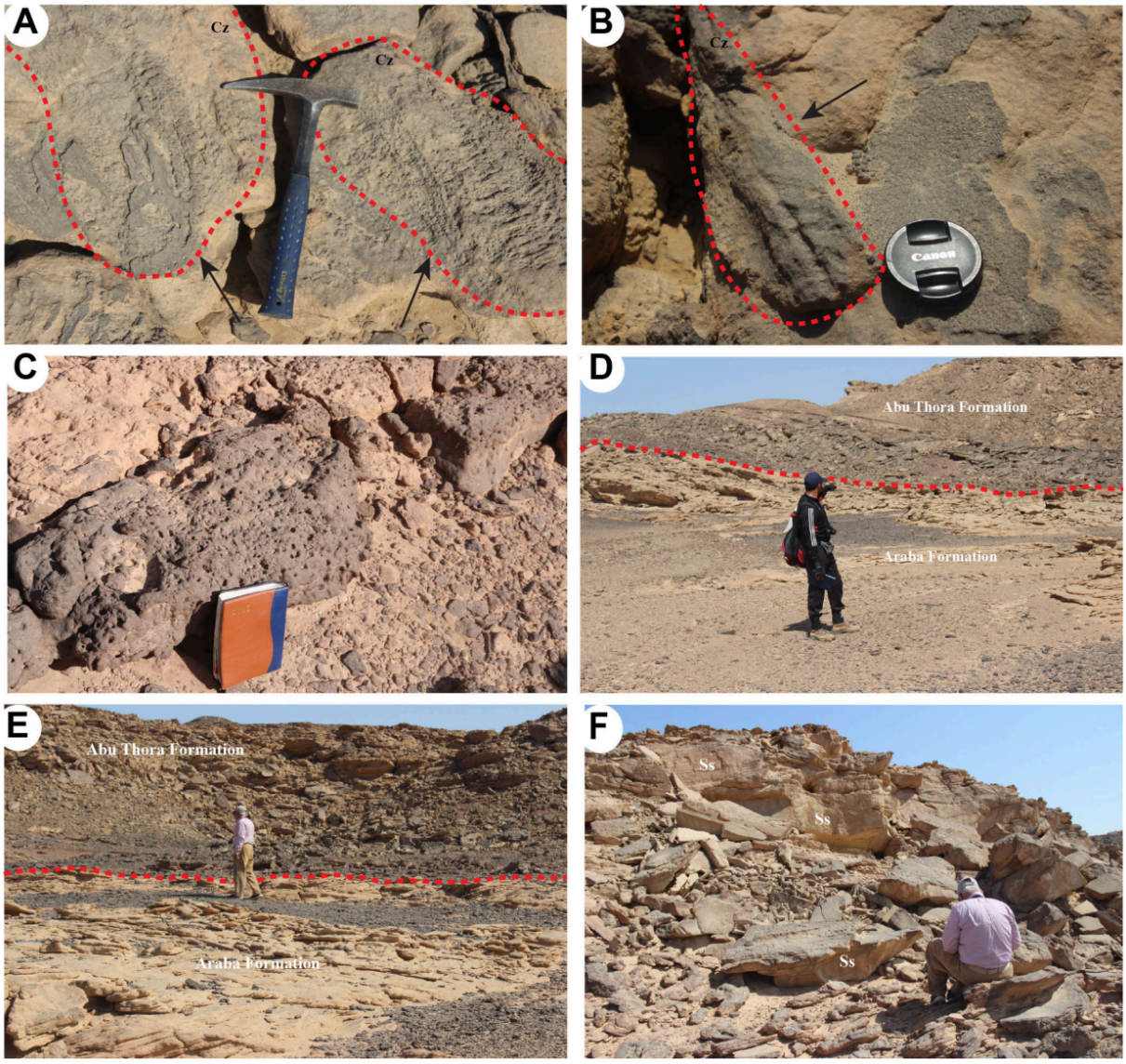

Figure 4. Upper Araba strata and the Araba–Abu Thora boundary. (**A**,**B**) Cruziana-like bilobed surface traces (Cz). (**C**) Burrows in upper Araba sandstone. (**D**,**E**) Sharp, mappable lithological transition from coarse Araba sandstone to finer Abu Thora strata. No basal lag or erosional relief is visible at the illustrated contact, which is interpreted as apparently conformable. (**F**) Thick sandstone beds in upper Abu Thora.

The upper boundary at QQ-05 is a sharp, mappable lithological transition into the finer and more heterolithic Abu Thora succession (Figure 4D,E). No basal lag or erosional relief was recognized at the illustrated contact; it is therefore described conservatively as apparently conformable rather than as proof of uninterrupted time equivalence. The change in sandstone character, finer siliciclastic intervals, and trace-fossil assemblage provides the field criterion for locating the boundary.

4.2. Abu Thora Formation

The Abu Thora Formation was introduced for Late Carboniferous siliciclastic successions of west-central Sinai [29] and has been widely used in subsequent Egyptian stratigraphic literature [30–36]. Along the Quseir–Qift Road, the name is applied to the heterolithic siliciclastic unit above Araba, recognized locally by sandstone–siltstone alternations, paleosol-bearing intervals, ferruginous and manganese-rich features, and plant- and root-related structures at the illustrated localities.

The two Abu Thora composite logs record thicknesses of 68–72 m (Figure 5A,B). The first vertical succession is anchored by QQ-07 and includes the restricted transition into Abu Durba at QQ-09; the second begins at the Araba–Abu Thora control QQ-05 and terminates at the Abu Thora–Malha contact QQ-08, where Abu Durba is absent. The lower Araba–Abu Thora boundary is a sharp, mappable lithological transition and is apparently conformable at the illustrated exposure (Figure 4D,E).

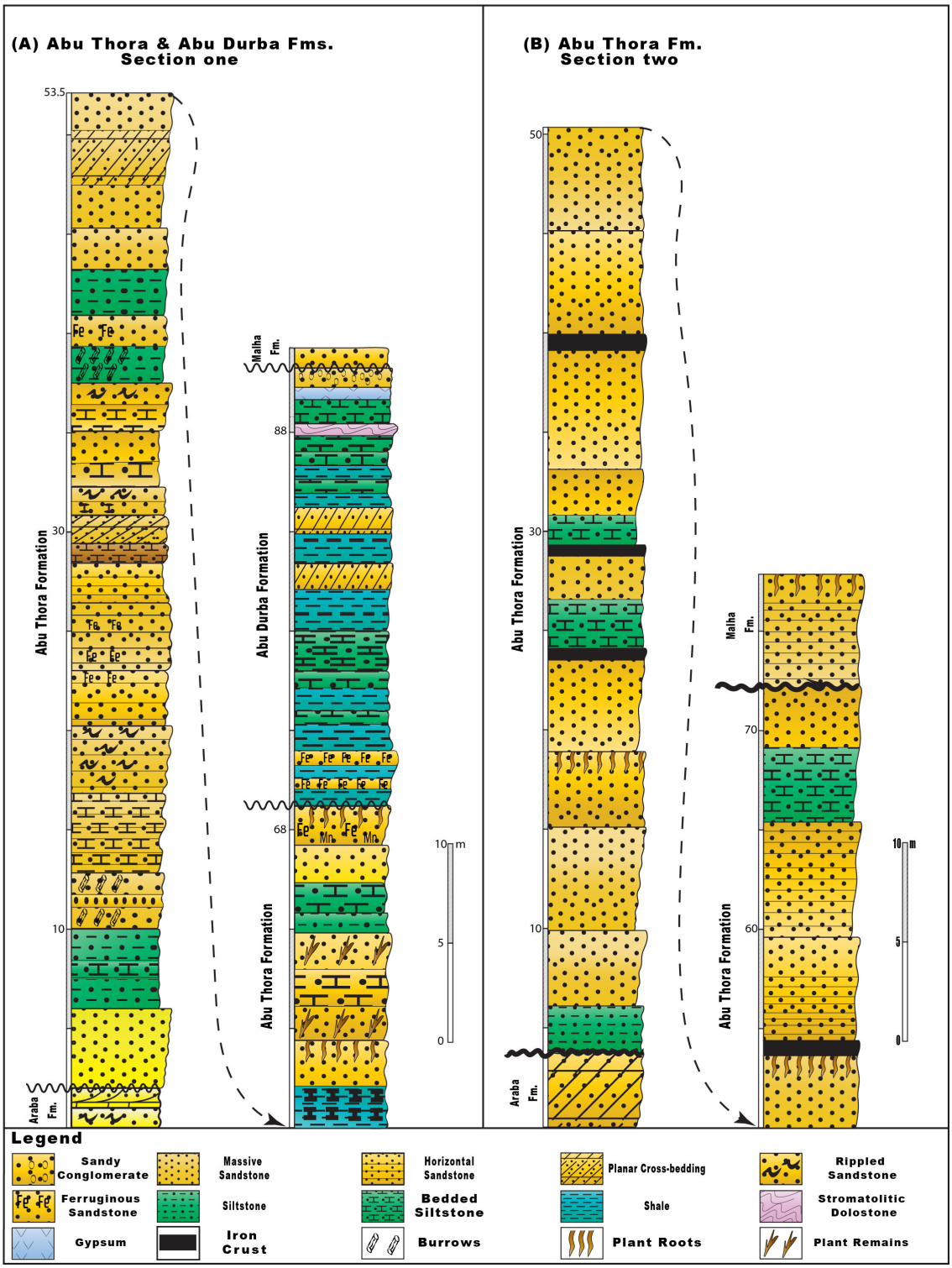

Figure 5. Composite logs of Abu Thora. (**A**) Abu Thora overlain by the restricted Abu Durba interval. (**B**) Abu Thora where Abu Durba is absent and Malha rests directly above.

The formation contains fine- to medium-grained sandstone, siltstone, heterolithic beds, paleosol horizons, and ferruginous to manganese-rich intervals. Alternation between sandstone-dominated and fine-grained intervals accounts for the vertical and lateral variability shown by the composite logs (Figures 5 and 6).

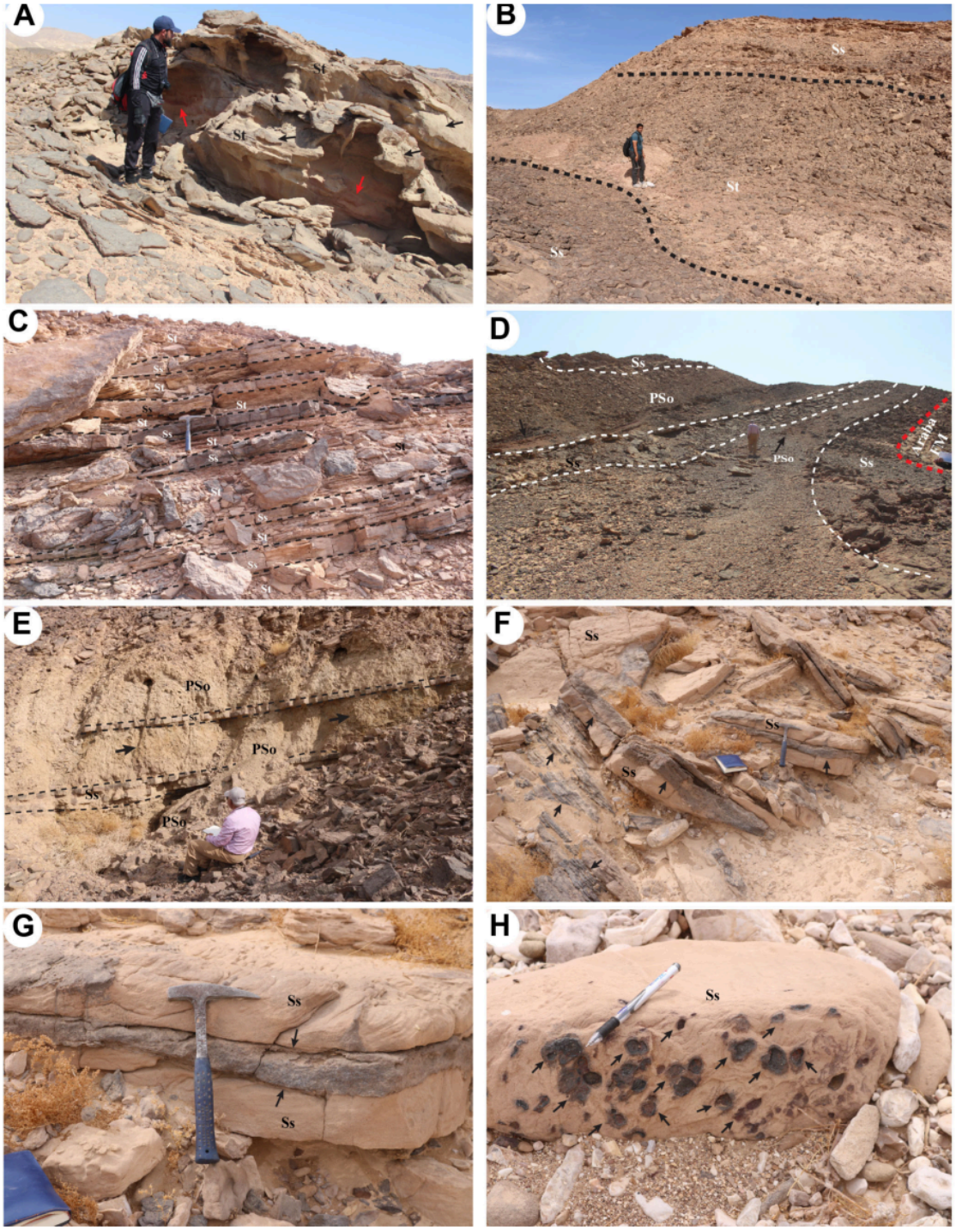

Figure 6. Field photographs showing representative lithological features of the Abu Thora Formation along the Quseir–Qift Road. (**A**,**B**) Varicoloured and relatively thick siltstone intervals (St). (**C**) Heterolithic sandstone (Ss) and siltstone (St) alternations. (**D**,**E**) Sandstone–paleosol cycles and multicoloured paleosol horizons (PSo) in the lower and upper parts of the Abu Thora Formation. (**F**,**G**) Manganese oxide coatings and films along sandstone beds, fractures, and bedding surfaces. (**H**) Discrete manganese oxide nodules within the sandstone matrix. The illustrated features highlight the heterolithic, paleosol-bearing, and manganese-rich character of the Abu Thora Formation.

Planar cross-bedding, ripple marks, horizontal lamination, channelized conglomeratic beds, and heterolithic bedding occur in the illustrated sections (Figure 7A–D). Together with fossilized wood, rhizoliths/root traces, and burrows (Figure 7E–H), these features support field recognition but are not treated as age-diagnostic evidence.

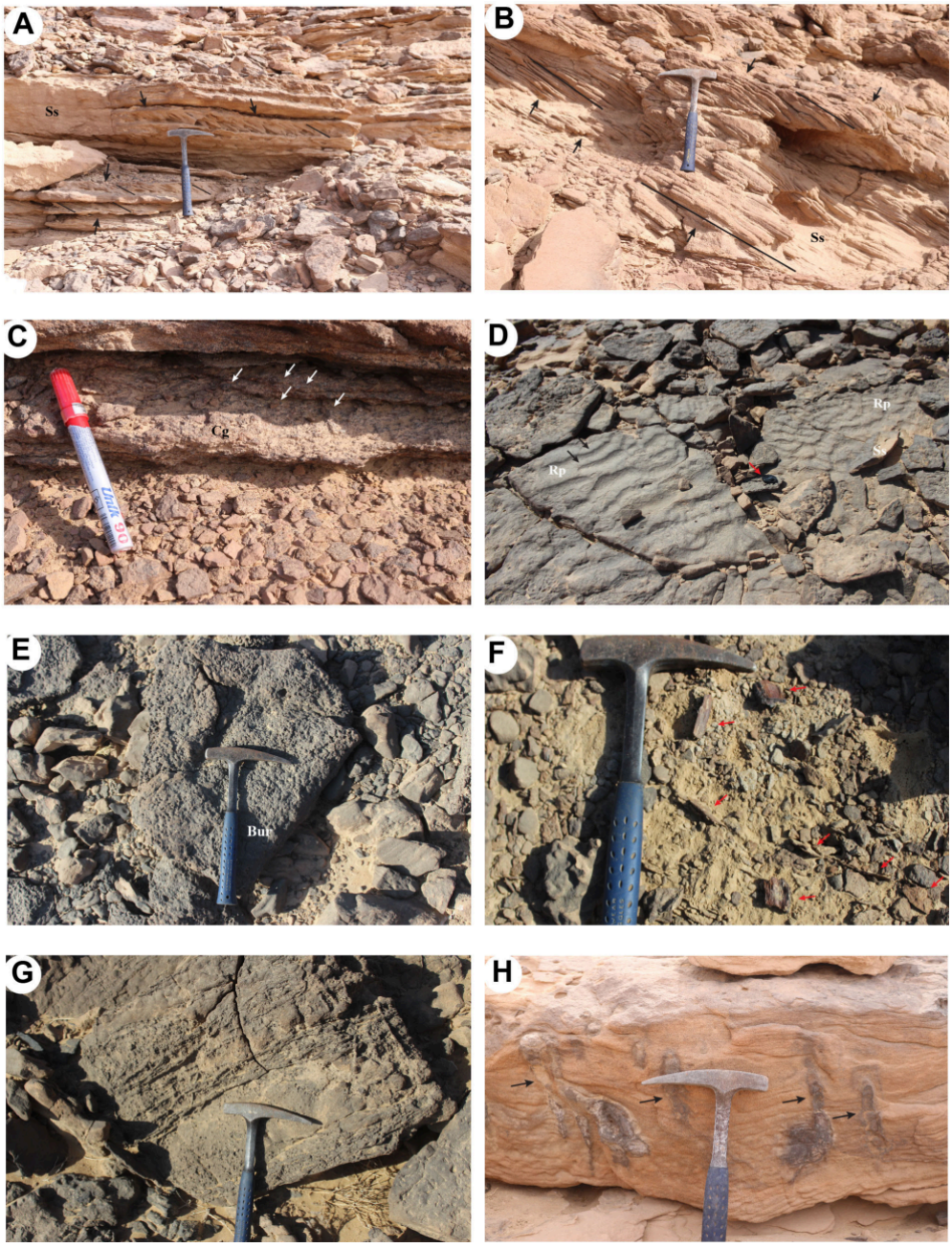

Figure 7. Field photographs showing representative sedimentary structures and biogenic features of the Abu Thora Formation along the Quseir–Qift Road. (**A**) Planar cross-bedding in sandstone beds (Ss) of the first measured section, with foreset laminae indicated by black lines and arrows. (**B**) Planar cross-bedding in sandstone beds (Ss) of the second measured section. (**C**) Close-up view of a thin conglomeratic bed (Cg) containing well-rounded quartz pebbles. (**D**) Well-preserved asymmetrical ripple marks (Rp) on Abu Thora sandstone bedding surfaces. (**E**) Burrow structures (Bur) within sandstone beds. (**F**) Close-up view of fossilized wood fragments. (**G**) Abundant rhizoliths/root traces within sandstone beds (Ss) in the upper part of the Abu Thora Formation, preferentially preserved in manganese-rich zones. (**H**) Close-up view of rhizolith morphology within manganese-stained sandstone. These features support the recognition of the Abu Thora Formation as a heterolithic, plant-bearing, locally bioturbated siliciclastic unit.

The plant, root, and burrow structures are supporting observations tied to the illustrated localities rather than defining criteria applied to every exposure.

The upper relationship varies laterally and is directly constrained by separate field controls. At QQ-09, Abu Durba overlies Abu Thora as the restricted claystone–dolostone–gypsum interval begins (Figure 8A). At QQ-08, Abu Durba is absent, and the erosional base of Malha rests directly on Abu Thora (Figure 8B). This alternative boundary relationship is a principal line of evidence that the Abu Durba interval is laterally restricted rather than a ubiquitous facies within Abu Thora.

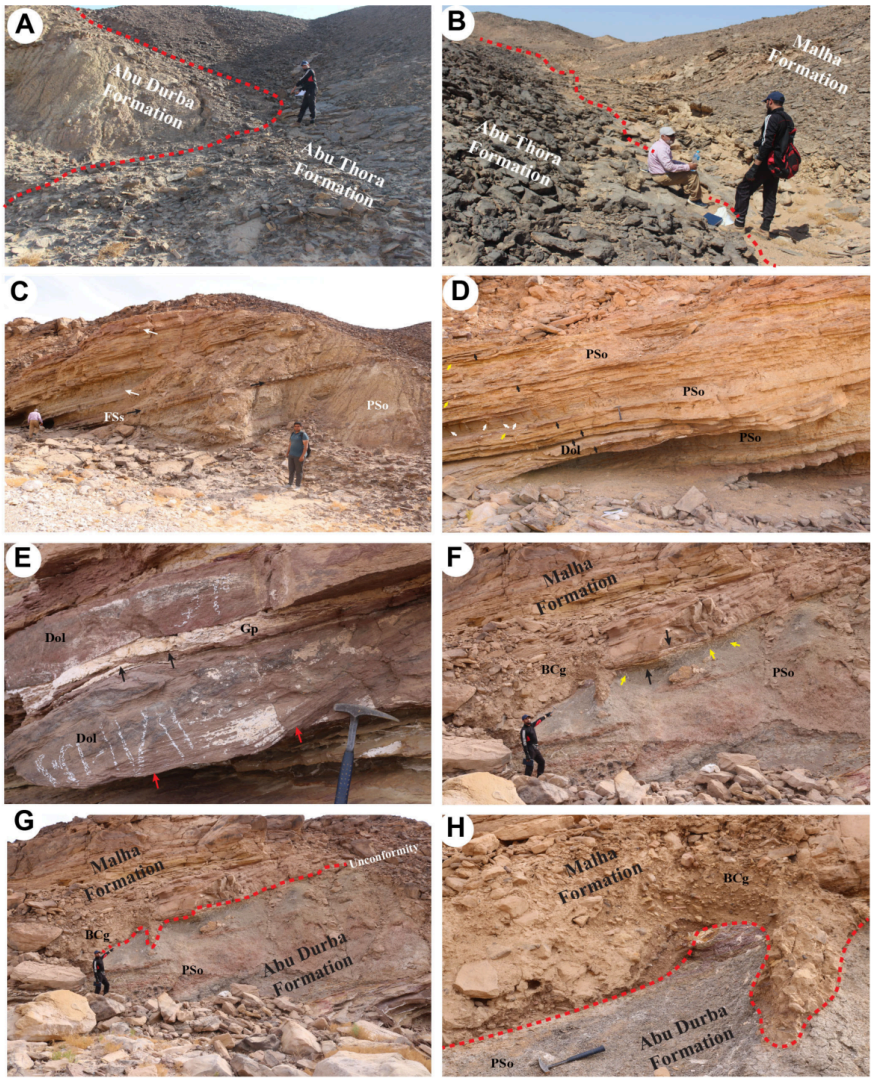

Figure 8. Field photographs of the upper contact relationships of the Abu Thora Formation and the lithological features and bounding contacts of the Abu Durba Formation along the Quseir–Qift Road. (**A**) Abu Thora Formation overlain by red siltstone of the Abu Durba Formation in the first measured section. (**B**) Abu Thora Formation overlain directly by cross-bedded sandstone of the Malha Formation in the second measured section, where Abu Durba is absent. (**C**) Cyclic Abu Durba succession of paleosol-rich claystone (PSo), ferruginous sandstone (FSs), dolostone, and thin gypsum layers. (**D**) Clay-rich paleosol (PSo) interbedded with ferruginous sandstone, thin dolostone beds (Dol), gypsum laminae, iron oxide nodules, and plant remains. (**E**) Stromatolitic dolostone (Dol) associated with gypsum layers (Gp). (**F**) Variegated upper paleosol of the Abu Durba Formation with root traces and massive gypsum, overlain by the basal conglomerate (BCg) of the Malha Formation. (**G**,**H**) Sharp erosional unconformity at the Abu Durba–Malha contact, marked by variegated paleosol below and coarse basal conglomerate above. These features document the restricted occurrence and distinctive claystone–dolostone–gypsum association of the Abu Durba Formation.

4.3. Abu Durba Formation

The Abu Durba/Durba Formation entered Egyptian stratigraphic usage through work in southern Sinai [25,26] and has since been discussed in regional Paleozoic syntheses and biostratigraphic studies [36–39]. In the study area it occurs only on the QQ-07/QQ-09 traverse between Abu Thora and Malha and is recognized by its claystone–dolostone–gypsum association, stromatolitic dolostone, and bounding contacts.

The restricted exposure is represented in one composite log and is approximately 24 m thick (Figure 5A). Its absence on the QQ-05–QQ-08 traverse provides direct lateral evidence that the unit is not continuously preserved across the mapped corridor.

Its lower boundary is a sharp lithological contact above Abu Thora, marked by the onset of claystone, dolostone, gypsum, and ferruginous sandstone (Figure 8A).

Paleosol-rich claystone, ferruginous sandstone, gypsum, dolostone, and stromatolitic dolostone form thin cyclic intervals in the illustrated exposure (Figure 8C–E). This association distinguishes Abu Durba from the siliciclastic units above and below.

The upper boundary is the sharp erosional unconformity at the base of Malha, where variegated fine-grained Abu Durba strata are overlain by Malha basal conglomerate (Figure 8F–H).

4.4. Malha Formation

The Malha Formation was introduced for variegated Lower Cretaceous siliciclastic strata at Wadi Malha on the western side of the Gulf of Suez [40,41]. In the study area, the name is applied to the sandstone–siltstone–claystone succession above Abu Durba where preserved, or directly above Abu Thora where Abu Durba is absent.

The two Malha composite logs are approximately 78 m thick (Figure 9A,B) and are controlled by two separate traverses: QQ-10 to the Malha–Bahariya contact at QQ-11, and QQ-08 to the second Malha–Bahariya contact at QQ-12 (Supplementary Table S1). The lower boundary is a major erosional unconformity above Abu Durba on the first traverse or directly above Abu Thora, where Abu Durba is absent on the second, and is marked by basal conglomerate (Figure 8G,H). These underlying units are correlated regionally with Carboniferous formations, but no local Carboniferous age is independently demonstrated.

Lower and upper lithological intervals can be followed in the logs but are used only as informal descriptive subdivisions. Sandstone–siltstone–claystone alternations, basal conglomerate, and a terminal ferruginous sandstone are the principal components (Figure 9A,B).

Fining-upward packages, planar to trough cross-bedding, convolute bedding, lateral pinch-out, silicified wood, and root traces occur in the illustrated sections (Figure 10A–F).

The Malha–Bahariya boundary is a sharp, non-erosional lithostratigraphic contact, placed between the terminal ferruginous Malha sandstone and the overlying Bahariya siliciclastic succession (Figure 10G,H).

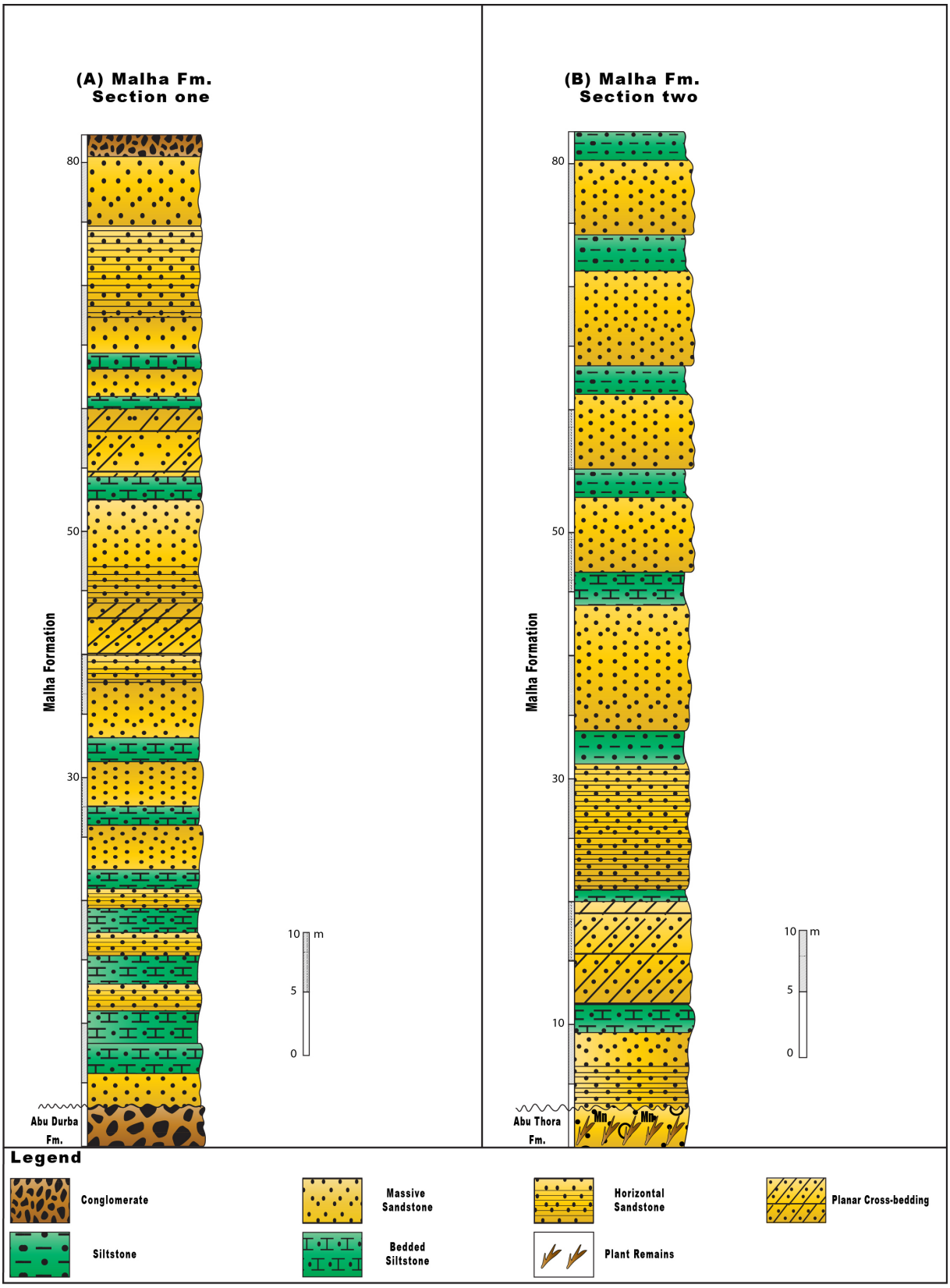

Figure 9. Composite logs of the Malha Formation. (**A**) First Malha composite log, controlled by the QQ-10–QQ-11 traverse. (**B**) Second Malha composite log, controlled by the QQ-08–QQ-12 traverse. Both logs show representative vertical stacking, thickness, and lower and upper boundary relationships.

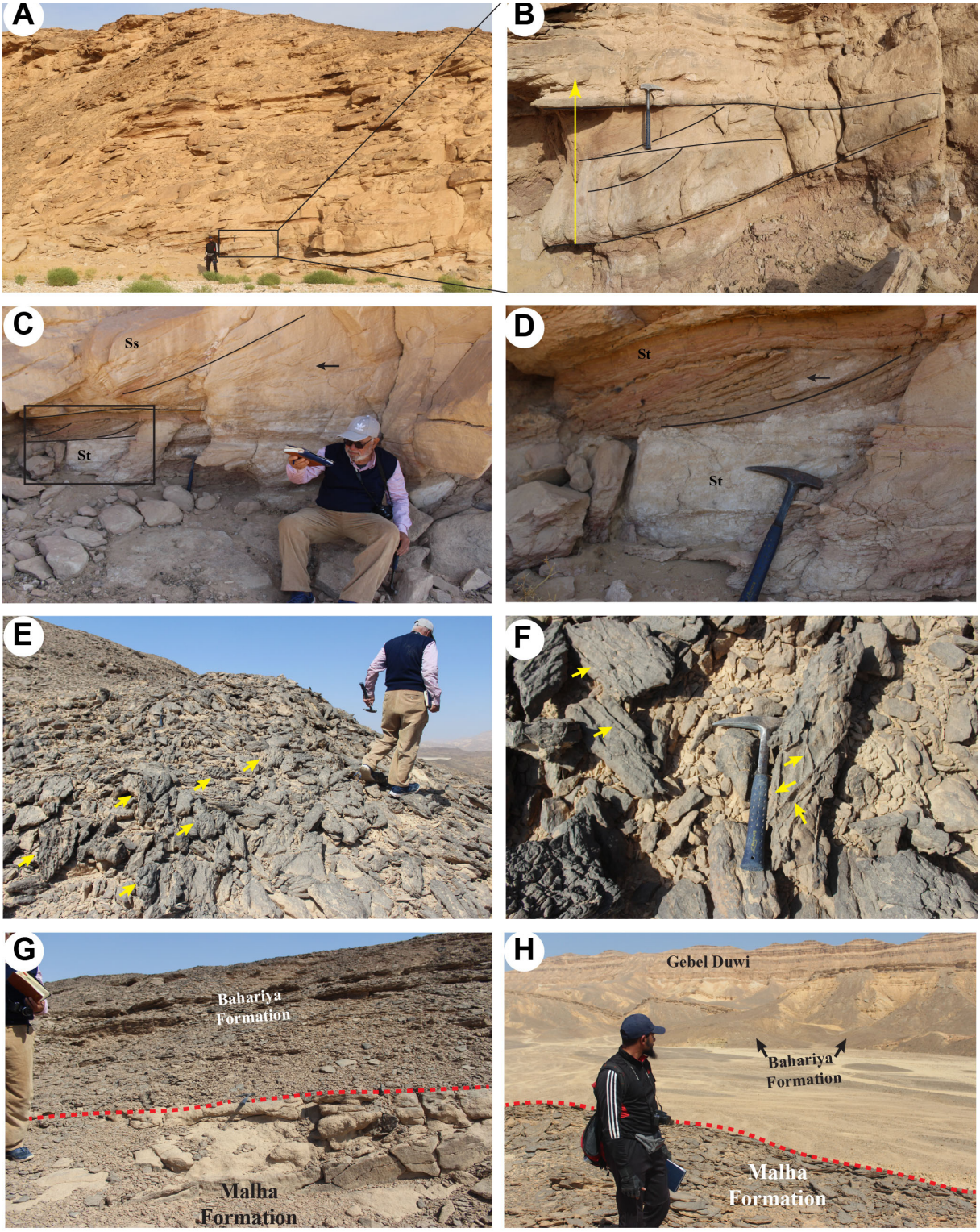

Figure 10. Field photographs of the Malha Formation along the Quseir–Qift Road. (**A**) Lower Malha interval in the first composite measured section, showing stacked fining-upward cycles. (**B**–**D**) Sandstone (Ss)–siltstone (St) alternations with well-developed trough cross-bedding in yellow to beige fine-grained sandstone (Ss). (**E**) Silicified wood trunks in the uppermost beds of the lower Malha interval. (**F**) Root traces within the uppermost layers of the lower Malha interval. (**G**) Black coarse-grained sandstone capped by a ferruginous crust at the top of the Malha Formation. (**H**) Sharp lithostratigraphic contact between the Malha Formation and the overlying Bahariya Formation in the second composite measured section. The illustrated features summarize the main field criteria used to recognize the Malha Formation and its upper boundary.

4.5. Bahariya Formation

The Bahariya Formation was defined for Cenomanian clastic deposits in the Bahariya Oasis [5,42–47]. Along the Quseir–Qift Road, the name is applied to the cyclic ferruginous sandstone–siltstone–claystone succession between Malha and Taref.

The Bahariya portions of the two Bahariya–Taref composite logs are controlled by QQ-11 and QQ-12 and record thicknesses of 37 and 60 m, respectively (Figure 11A,B); QQ-13 provides an additional internal boundary control within Bahariya. The lower boundary is the sharp, non-erosional lithostratigraphic contact above Malha.

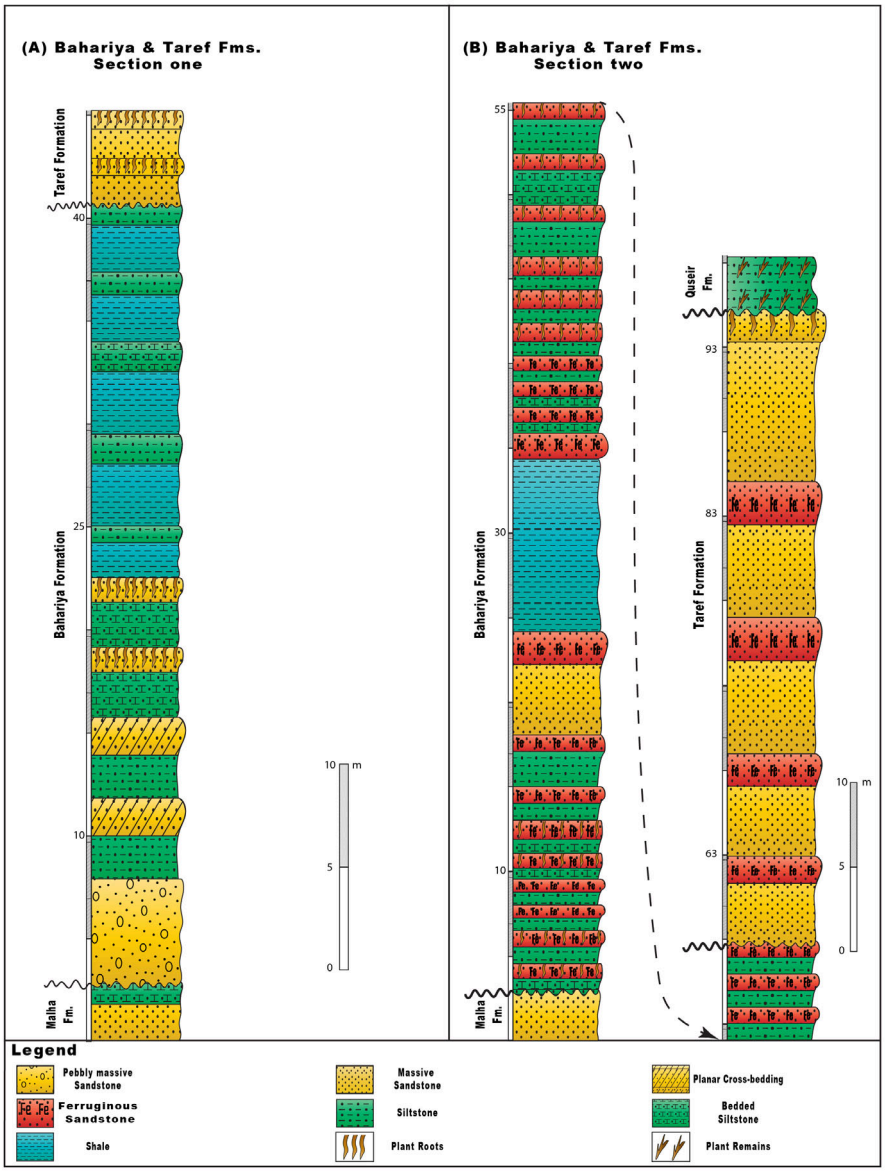

Figure 11. Composite logs of the Bahariya–Taref interval. (**A**) First composite log, controlled by QQ-11 and QQ-14. (**B**) Second composite log, controlled by QQ-12 and QQ-15. The logs show thickness variation, vertical stacking, and the erosional Bahariya–Taref boundary.

The formation comprises fine- to medium-grained sandstone, siltstone, claystone, ferruginous bands or crusts, and paleosol-bearing intervals arranged in repeated siliciclastic cycles (Figures 11 and 12A–D).

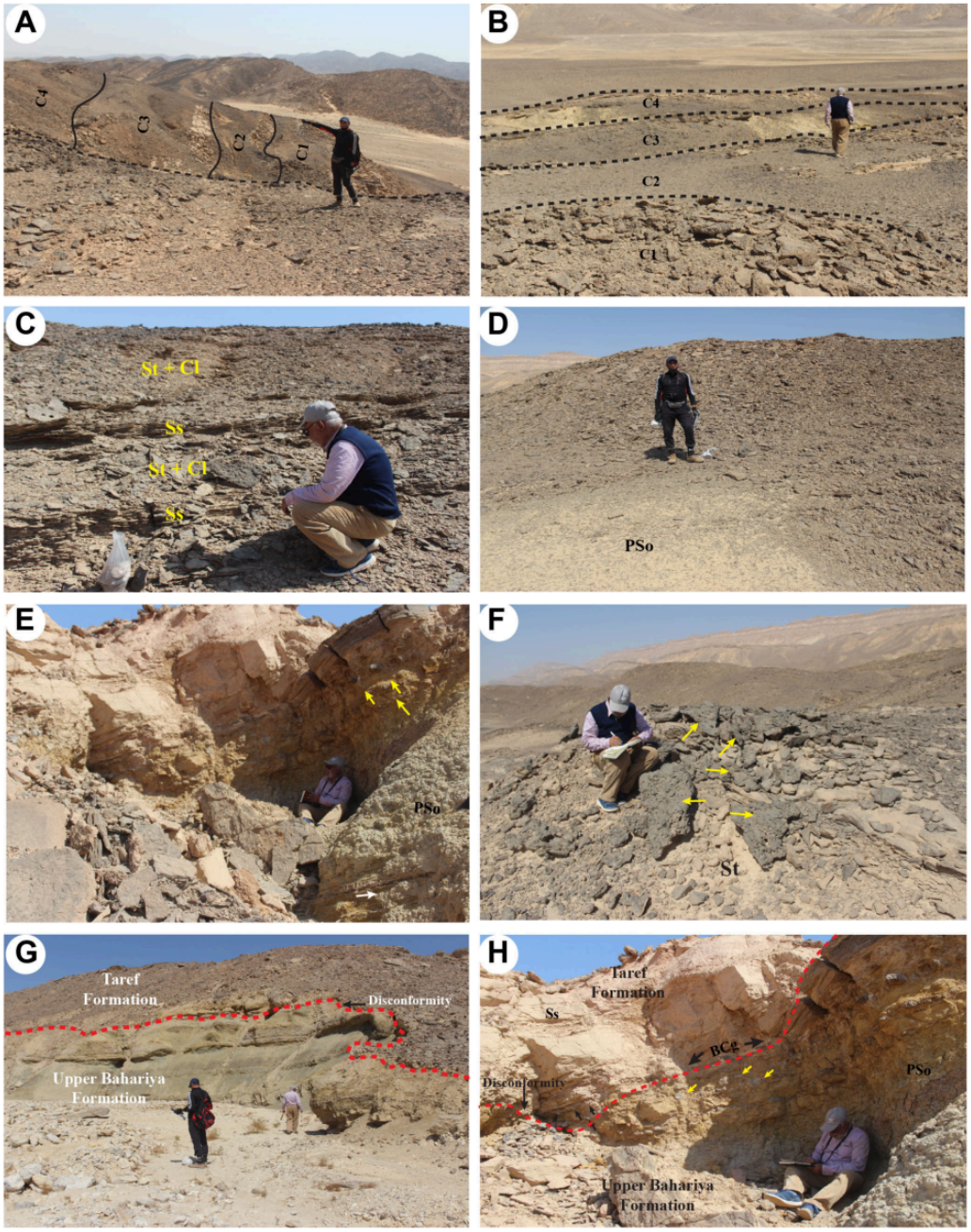

Figure 12. Field photographs of the Bahariya Formation along the Quseir–Qift Road. (**A**–**C**) Fining-upward sandstone (Ss)–siltstone (St)–claystone (Cl) cycles (C1–C4) in the lower and upper Bahariya intervals. (**D**) Paleosol horizons (PSo) capping sedimentary cycles in the lower Bahariya interval. (**E**) Uppermost paleosol horizon with root traces, overlain by massive red to purple fine-grained sandstone. (**F**) Root-bearing siltstone horizons capping several cycles. (**G**) Ferruginous sandstone with iron nodules and vertical bioturbation at the top of the Bahariya Formation, sharply overlain by the basal conglomerate of the Taref Formation. (**H**) Ferruginous sandstone and paleosol-bearing siltstone (PSo) with iron nodules below the basal conglomerate (BCg) of the Taref Formation. These features summarize the cyclic siliciclastic architecture, paleosol-bearing intervals, ferruginous character, and sharp upper contact of the Bahariya Formation.

Its cyclic organization, ferruginous and paleosol-bearing intervals, and position between Malha and Taref provide the principal local recognition criteria.

Horizontal lamination, planar and festoon cross-stratification, ripple lamination, desiccation cracks, root traces, vertical burrows, and plant debris occur in the illustrated

intervals (Figure 12E,F). These are supporting observations rather than criteria assumed at every exposure.

The upper boundary is a sharp erosional contact marked by the abrupt onset of coarser, locally pebbly Taref sandstone (Figure 12G,H).

4.6. Taref Formation

The Taref Formation was introduced for a sandstone-dominated unit of the Nubian Sandstone succession in the Kharga Oasis region [48] and has been applied to comparable Upper Cretaceous siliciclastic successions [16,41,49]. In the study area it forms the uppermost recognized Nubian Sandstone unit, between Bahariya and the Quseir Formation.

The Taref portions of the two Bahariya–Taref composite logs are controlled by QQ-14 and QQ-15 and record thicknesses of 7 and 37 m, respectively. QQ-15 also fixes the erosional Bahariya–Taref boundary, marked by a coarser lag and pebbly sandstone (Figures 11 and 12G,H).

Taref consists mainly of ferruginous quartzose sandstone and pebbly sandstone, with subordinate siltstone and shale. A greenish-gray siltstone interval occurs locally upward; no petrographic mineral identification is inferred from its field colour.

The basal lag, ferruginous sandstone, and pebbly intervals distinguish Taref from the finer and more cyclic Bahariya succession below (Figure 12G,H).

Planar cross-bedding, horizontal and ripple lamination, scours, intraformational conglomeratic beds, and ferruginous crusts occur in the illustrated exposures (Figure 13A,B). Plant remains and bioturbation are local supporting observations and are not used as age criteria.

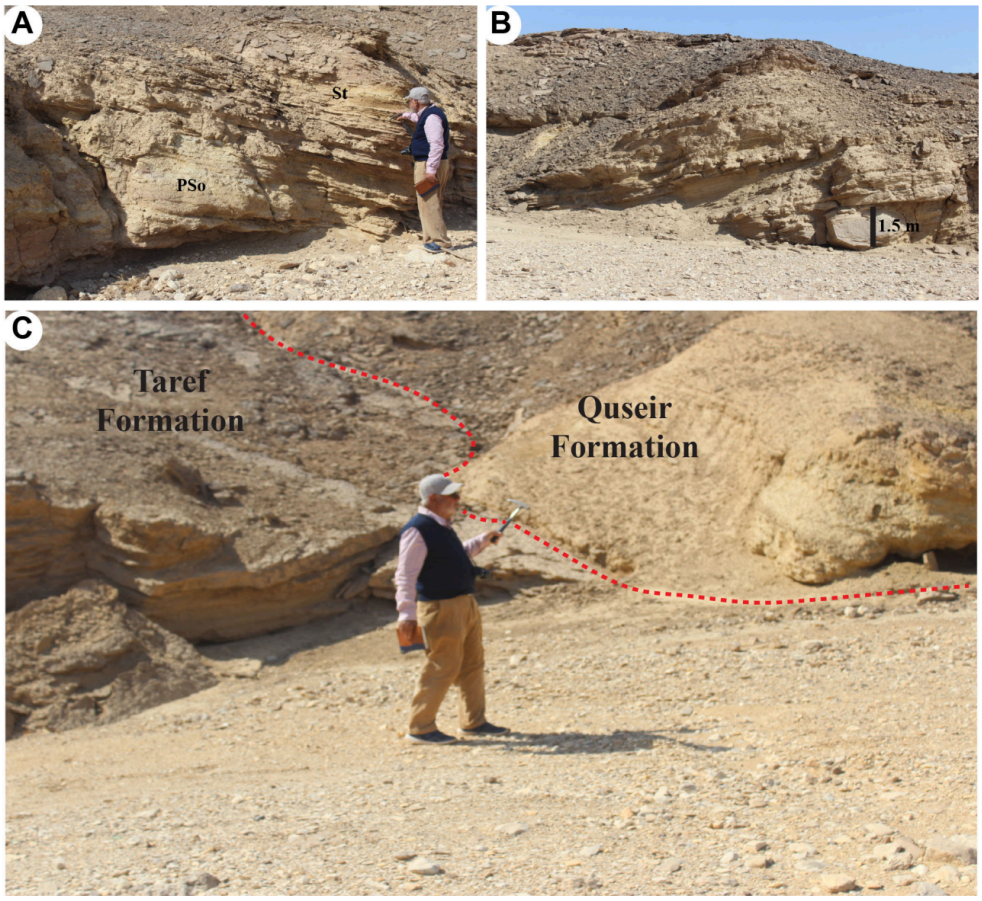

Figure 13. Field photographs showing representative upper intervals and the upper contact of the Taref Formation along the Quseir–Qift Road. (**A**) Upper part of the second composite section of the

Taref Formation, showing an upward transition from medium-grained, well-sorted sandstone to paleosol horizons (PSo) and greenish-gray siltstone (St). (**B**) Medium- to coarse-grained, moderately sorted laminated sandstone capped by fine siltstone layers in the upper part of the first composite Taref section. (**C**) Sharp lithostratigraphic contact between coarse, cross-bedded ferruginous sandstone of the Taref Formation and the overlying siltstone and shale of the Quseir Formation. These features document the upper lithological organization of the Taref Formation and its boundary with the overlying Quseir Formation.

The upper boundary is a sharp lithostratigraphic contact with the Quseir Formation, marked where exposed (Figure 13C) by a shift from coarse ferruginous Taref sandstone to finer Quseir siltstone and shale.

5. Lithostratigraphic Correlation and Discussion

The discussion evaluates first the strength and limitations of the local six-unit framework and then the regional correlations assigned to those field-defined packages. Depositional interpretations are retained only as supporting implications and are not used to define formations or to establish age equivalence.

5.1. Local Framework: Change from Previous Interpretations, Strengths, and Limitations

Compared with the earlier products summarized in Table 1, the present framework changes the local stratigraphic resolution rather than the regional nomenclature. It places six established formation names onto field-defined packages along the Quseir–Qift corridor using two independent sets of vertical controls, explicit boundary localities, and alternative contact relationships. It does not supersede the earlier regional maps or sedimentological studies; instead, it tests whether their broad Nubian Sandstone interval can be resolved reproducibly at the formation scale in this specific corridor.

The strongest local evidence is provided by boundaries or packages with distinctive physical expression: the basement–Araba nonconformity and basal conglomerate, the package-scale transition from Araba to heterolithic Abu Thora, the restricted claystone–dolostone–gypsum Abu Durba interval, the erosional basal conglomerate of Malha, and the erosional coarsening at the Bahariya–Taref boundary. Repeated Malha–Bahariya contacts on two traverses and the contrasting preservation of Abu Durba further show that the subdivision is not based on a single composite section.

The framework nevertheless has explicit limitations. Exposure is discontinuous, lateral facies variation is substantial, Abu Durba is locally restricted, and some contacts are defined by persistent lithological transitions rather than regionally exposed unconformity surfaces. Fossil and trace-fossil evidence is limited and was not used as independent local age control. The framework therefore depends strongly on package-scale lithology, stratigraphic position, and contacts; where those criteria converge less strongly, the assigned regional formation name is correspondingly more provisional. At the 1:25,000 map scale, Abu Durba is shown with Abu Thora and is resolved separately only in the logs and field-contact data.

Confidence in a local boundary is highest where the same contact relationship is repeated or bracketed by multiple field controls and lower where exposure gaps require interpolation between controls. The map therefore represents a field-constrained interpretation of discontinuous outcrop, not a claim that every contact is continuously exposed. This distinction is important for future testing of the framework at additional sections along the Eastern Desert.

The local packages are next compared with established formations elsewhere in Egypt. This second step is deliberately separated from local recognition because lithostratigraphic similarity alone does not demonstrate age equivalence.

5.2. Regional Correlation and Uncertainty

For each formation, Table 3 separates evidence observed in the Quseir–Qift succession from the comparison made with a published reference area and states the limitation on that correlation.

For orientation only, published reference-area assignments commonly place the Araba Formation in the Cambrian [25–28], the Abu Thora Formation in the Late Carboniferous [29–36], the Abu Durba/Durba Formation within the Carboniferous [25,26,36–39], the Malha Formation in the Lower Cretaceous [40,41], the Bahariya Formation in the Cenomanian [5,42–47], and the Taref Formation within the Upper Cretaceous [16,41,48,49]. These are literature-based age contexts for the correlated reference units, not independent age determinations for the Quseir–Qift succession; possible diachroneity and interbasinal facies convergence therefore remain explicitly acknowledged.

Table 3 intentionally prevents the correlation argument from becoming circular: the first evidence column contains only observations made in the study area, whereas the next columns state the external comparison and its limitation. Araba and Abu Durba have particularly distinctive local boundary/lithology combinations; Abu Thora is supported by its ordered position and heterolithic/paleosol-bearing architecture. The younger Malha, Bahariya, and Taref packages are well separated locally by contacts and vertical organization, but their long-distance name assignments remain more dependent on regional lithostratigraphic similarity.

Independent age constraints from other Egyptian localities provide regional context but are not transferred directly to the Quseir–Qift succession. Paleomagnetic work on the Araba and Naqus formations at Wadi Dakhl yielded locality-specific Paleozoic age interpretations [27], whereas Tournaisian miospore assemblages have been reported from subsurface Nubia intervals in the Gulf of Suez [50]. These studies illustrate why age control obtained elsewhere cannot by itself establish the age of lithologically similar packages in the present corridor.

Loose fossiliferous debris observed on the surface above Malha is interpreted as reworked material from younger strata and is excluded from age assignment and correlation. Likewise, the morphology-based trace labels in Araba and Abu Thora are not treated as index fossils. No local correlation is therefore upgraded to time equivalence on the basis of these observations.

The six-formation terminology is adopted as the best-fitting local working framework for the observed succession, with formation-specific uncertainty stated in Table 3. The correlations should be tested by future biostratigraphic, geochronologic, or additional section data rather than treated as proof of regional isochrony.

Accordingly, the principal result is a locally testable lithostratigraphic subdivision; it is not a definitive regional solution to Nubian Sandstone nomenclature or chronology.

Table 3. Separation of local field evidence from regional lithostratigraphic correlation for the six formations recognized along the Quseir–Qift Road.

Local Formation	Evidence Observed in Quseir–Qift Study Area	Correlated Established Unit/Reference Area	Reference-Area Comparison Used	Correlation Limitation/Confidence	Key Refs.
Araba Formation	Basement nonconformity; basal conglomerate and pebbly sandstone; coarse-to-finer vertical organization; Cruziana-like and Skolithos-like field morphologies.	Araba Formation; Sinai and Wadi Araba–Umm Bogma framework	Comparable basal position above crystalline basement and sandstone-dominated lower Paleozoic succession; recent Wadi Dakhl work provides independent regional age context.	Strong local package recognition; the regional name is lithostratigraphically compatible, but no independent local Cambrian age exists and field trace labels are not formal index-fossil determinations.	[25–28]
Abu Thora Formation	Heterolithic sandstone–siltstone succession; paleosol-bearing intervals; plant/root structures; ferruginous and Mn-rich features; position above Araba.	Abu Thora Formation; west-central Sinai	Comparable heterolithic siliciclastic architecture and stratigraphic position within established Carboniferous successions.	Local recognition is moderate to strong; exact Carboniferous age equivalence is not independently demonstrated and facies convergence remains possible.	[29–36]
Abu Durba Formation	Restricted claystone–dolostone–gypsum package with stromatolitic dolostone; sharp contacts; present on QQ-07/QQ-09 traverse and absent on QQ-05–QQ-08 traverse.	Abu Durba/Durba Formation; Sinai	Comparable restricted fine-grained, dolomitic/evaporitic interval and stratigraphic position above Abu Thora.	Distinctive local package but limited lateral exposure; exact age equivalence with Sinai is untested locally.	[25,26,36–39]
Malha Formation	Erosional basal conglomerate above Abu Durba or directly above Abu Thora; sandstone–siltstone–claystone succession; terminal ferruginous sandstone.	Malha Formation; Gulf of Suez/Wadi Malha region	Comparable basal erosional surface/conglomeratic entry and variegated siliciclastic succession.	The local boundary framework is strong; the regional formation name and Early Cretaceous age remain correlation-based rather than locally dated.	[40,41]
Bahariya Formation	Cyclic ferruginous sandstone–siltstone–claystone succession with paleosol-bearing intervals; positioned between Malha and Taref; repeated on two traverses.	Bahariya Formation; Bahariya Oasis	Comparable cyclic ferruginous siliciclastic architecture and paleosol-bearing intervals.	Correlation is provisional because the reference area is in a different basin and similar continental-to-marginal siliciclastic facies can recur; no local Cenomanian age is independently established.	[5,42–47]
Taref Formation	Upper position; erosional basal lag; ferruginous and pebbly sandstone; upward-fining interval; contact below Quseir.	Taref Formation; Kharga/Western Desert	Comparable upper Nubian Sandstone position, coarse ferruginous sandstone character, and relationship below Quseir-type finer strata.	Local package recognition is strong, but regional age and isochrony are not independently demonstrated.	[16,41,48,49]

5.3. Depositional-Environment Implications

The environmental interpretations below are deliberately brief and subordinate to the lithostratigraphic argument. They are based on observed facies associations and are presented as plausible depositional implications, not as independent evidence for formation identity or regional age correlation.

The basal conglomerate, pebbly channelized sandstone, scours, and large-scale cross-bedding of lower Araba are consistent with high-energy fluvial transport. Herringbone cross-bedding, hummocky cross-stratification, ripples, and burrowed upper beds suggest an upward increase in tidal to shallow-water influence. Abu Thora heterolithic bedding and ripples, together with paleosols, root traces, and wood, are consistent with tidally influenced fluvial–estuarine to coastal-plain conditions and repeated emergence.

The gypsum-bearing claystone, dolostone, and stromatolitic dolostone of Abu Durba suggest a restricted evaporitic marginal setting, plausibly tidal-flat to lagoonal, but the available field evidence does not uniquely distinguish among restricted shallow-water subenvironments. The erosive base, basal conglomerate, cross-bedded sandstone, fining-upward packages, siltstone–claystone intervals, wood, and root traces of Malha are consistent with fluvial channels and associated floodplain deposition.

Bahariya fining-upward cycles, paleosols, desiccation cracks, root traces, and local bioturbation are consistent with fluvial to floodplain/delta-plain deposition with possible intermittent marginal influence. Taref begins with an erosional pebbly lag and cross-bedded ferruginous sandstone consistent with high-energy channel deposition and fines upward into siltstone and paleosol-bearing intervals compatible with lower-energy floodplain to coastal-plain conditions. These interpretations remain facies-based and do not control the formation correlations.

5.4. Implications for Nubian Sandstone Terminology

Nubian Sandstone remains useful as a broad regional field term, but its use alone does not express the six field-defined packages recognized along the Quseir–Qift corridor. Formation-scale description provides a more testable local framework while retaining established Egyptian formation names.

This is an application of existing nomenclature, not a formal revision of lithostratigraphic nomenclature and not the establishment of new units. The framework is intentionally local, and the more uncertain questions of interbasinal age equivalence remain separate from field recognition.

6. Conclusions

1. Eight composite logs tied to 18 GPS-referenced localities distinguish six formation-scale packages along the Quseir–Qift Road: Araba (77.5–84.5 m), Abu Thora (68–72 m), the restricted Abu Durba interval (approximately 24 m), Malha (approximately 78 m), Bahariya (37–60 m), and Taref (7–37 m). The logs are anchored by principal section controls and supplemented by boundary and lateral-continuity localities rather than derived by averaging all sites.
2. The most diagnostic local boundaries are the basal Araba nonconformity, the sharp Araba–Abu Thora lithological transition that is apparently conformable at the illustrated contact, the restricted Abu Durba package and its erosional upper boundary, the Malha erosional base above Abu Durba or Abu Thora, the repeated Malha–Bahariya contacts, and the erosional Bahariya–Taref boundary. The local absence of Abu Durba on one traverse demonstrates that lateral preservation varies within the corridor.
3. Facies associations are consistent with a mainly fluvial succession modified locally by tidal or shallow-water influence in Araba and Abu Thora, a restricted evaporitic

marginal setting in Abu Durba, and fluvial to floodplain or marginal settings in the younger units. These environmental interpretations support the field description but do not define the formations or establish their ages.

4. The six names provide a practical local working lithostratigraphic framework, but their ages remain regional correlation-based assignments. In the absence of independent local biostratigraphic or geochronologic control, exact time equivalence and isochrony across Egyptian basins are not demonstrated. The study therefore offers a testable local subdivision rather than a formal nomenclatural revision or a definitive regional solution for the Nubian Sandstone.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/geosciences16090348/s1, Table S1: GPS-referenced field localities, field roles, composite-log associations, and boundary/lateral-continuity contributions.

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Data Availability Statement: The field observations, composite logs, and mapping data supporting this study are reported in the article. Supplementary Table S1 provides the exact coordinates, field roles, composite-log associations, and boundary/lateral-continuity contributions of all 18 field localities; additional field records are available from the corresponding author upon reasonable request.

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