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The Paleozoic formations of the Al-Qassim Province in Saudi Arabia as potential sites for geotourism

Paleozoiczne formacje prowincji Al-Qassim w Arabii Saudyjskiej jako potencjalne obiekty geoturystyczne

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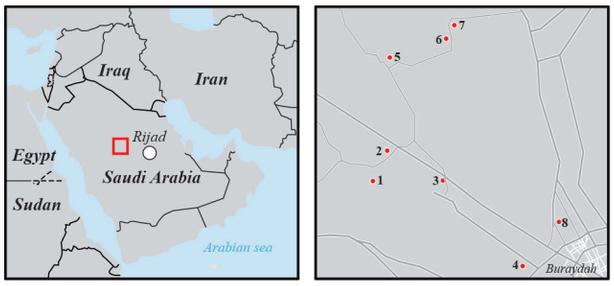

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Abstract: *The Paleozoic formations in the Middle East contain some of the world's richest petroleum deposits, as they include excellent source and reservoir rocks. The Paleozoic rocks were deposited on the northern continental shelf of the Gondwanan continent at relatively high latitudes, and provide evidence of the Late Ordovician glacial event and associated sea-level changes. They also contain unique fossil remains. The Paleozoic formations exposed in the Al-Qassim Province in Saudi Arabia are well-suited to become important sites for geotourism. Because the sedimentary formations are well-exposed and are easily accessible, they have strong capacity for development as tourist destinations. In this paper, we describe eight localities and their significance as potential educational sites for geology and palaeontology, as well as the archeological and economic significance of the Paleozoic formations of Saudi Arabia. The cultural and tourist infrastructure is summarised and a two-day field excursion is proposed.*

Keywords: *geology, palaeontology, Paleozoic, geosites, Saudi Arabia*

Treść: *Utwory paleozoiku na Bliskim Wschodzie reprezentowane są zarówno przez skały macierzyste, jak i zbiornikowe, dlatego zawierają bogate złoża ropy naftowej. Zostały one zdeponowane na kontynentalnym szelfie Gondwany w chłodnym klimacie i wykazują ślady warunków glacjalnych i zmian poziomu morza związanych z glacjacją. Występują w nich także unikalne skamieniałości. Formacje paleozoiku w prowincji Al-Qassim w Arabii Saudyjskiej mają duży potencjał dla geoturystyki. Ponieważ są one łatwo dostępne i dobrze odsłonięte, mogą służyć jako ciekawe atrakcje turystyczne. W niniejszej pracy opisano osiem obiektów geoturystycznych, przedstawiając ich geologiczną (w tym paleontologiczną) charakterystykę wraz z ekonomicznym znaczeniem badanych formacji. Proponując dwudniową wycieczkę terenową po utworach paleozoiku, wskazano także dwa obiekty archeologiczne. Omówiono również infrastrukturę kulturalną i turystyczną.*

Słowa kluczowe: *geologia, paleontologia, paleozoik, obiekty geoturystyczne, Arabia Saudyjska*

Introduction

Due to the recent introduction of tourist visas, Saudi Arabia is rapidly becoming an attractive tourist destination for the adventurous traveller. Centuries ago, the Al-Qassim (sometimes spelled Qasim) region was an important stopover for pilgrims on their way to Mecca. Nowadays, Al-Qassim is a vital agricultural and economic centre in Saudi Arabia and is becoming a popular tourist destination. The outcrops in the Al-Qassim region provide a glimpse into the changing climates of the northern coast of Gondwana during the Paleozoic era.

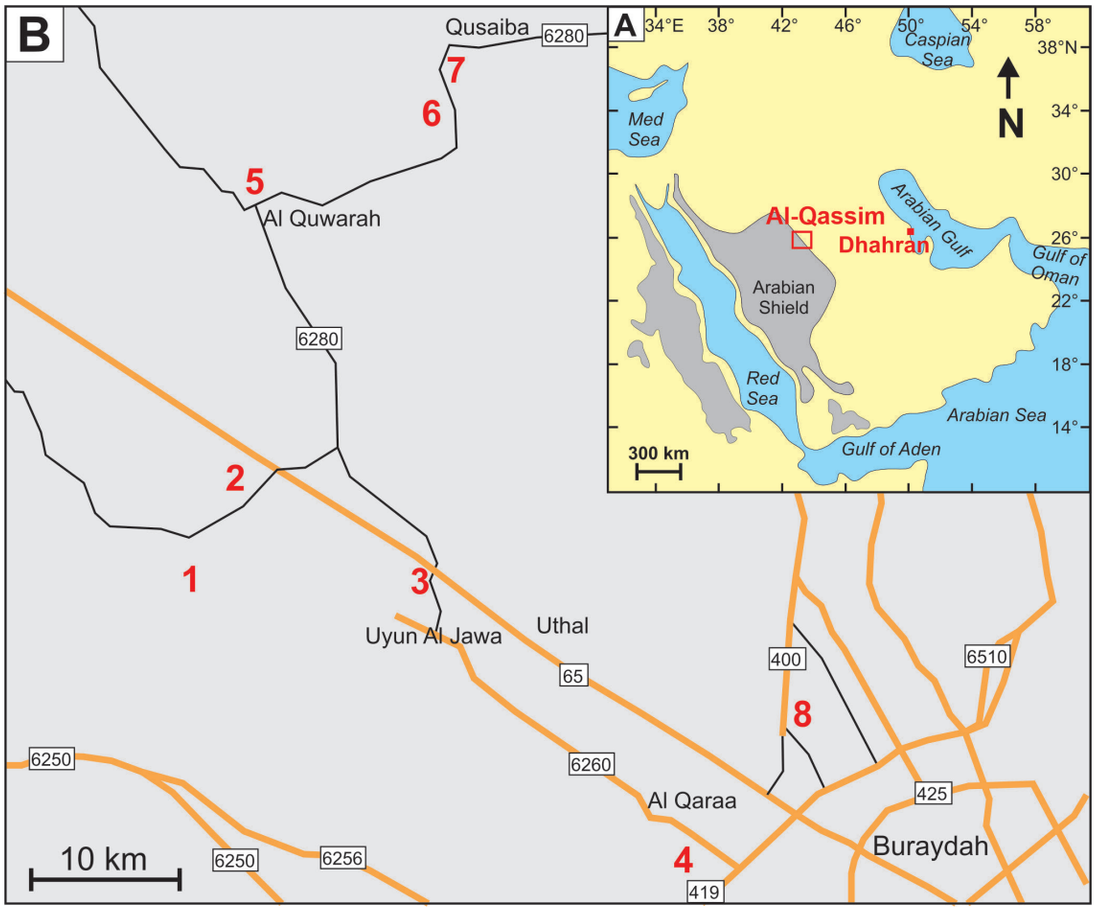

Fig. 1. Location of the geotouristic localities in the Al-Qassim Province of Saudi Arabia: A – insert map showing the position of the Al-Qassim Province on the Arabian Peninsula; B – geotouristic localities numbered in red. Base map from Google Maps

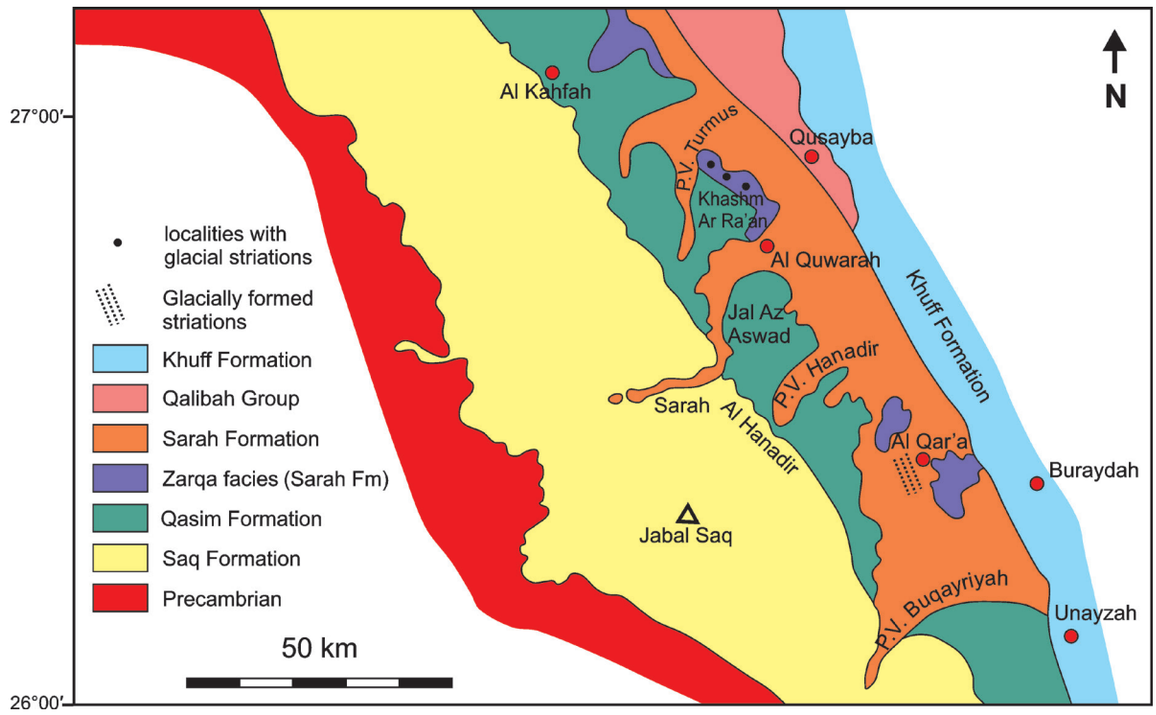

Fig. 2. Simplified geological map of the Al-Qassim Province, modified after Vaslet (1990)

These Paleozoic formations store enormous riches of hydrocarbons, which drive the economy of Saudi Arabia and surrounding countries through oil and gas production. The best and most accessible exposures of these oil and gas-bearing formations are found near Buraydah (sometimes written as Buraidah) (Fig. 1).

Al-Qassim is one of the thirteen provinces in Saudi Arabia and its capital is Buraydah (population 467,410 according to the 2010 census). Qassim University is the main higher education institution in the province, and is currently expanding its campus after becoming a co-educational institution. The local economy has been traditionally based on agriculture. While the region is most famous for dates, other important crops include wheat, citrus fruits, and melons. Modern green houses are used to grow an expanded range of fruits and vegetables. Camel and sheep are important livestock, integral to the economy and culture. One of the largest camel markets in the world is located in the outskirts of Buraydah. The regional source of water is the Cambrian sandstone aquifer, and bottled drinking water and soft drinks from Al-Qassim are available on supermarket shelves across the Middle East.

Geological exploration in the Al Qassim region began after the discovery of petroleum by the Standard Oil Company of California in 1935, and formations from this area were mentioned in the *Geology of the Arabian Peninsula: Sedimentary Geology of Saudi Arabia* by Powers *et al*. (1966). The eight geosites described below are located to the north of the Buraydah, and most are near the main highway leading north. The Paleozoic stratigraphy can be described as a slightly tilted layer cake, with rock units becoming progressively younger in a northeasterly direction (Fig. 2). Paleozoic sediments were deposited on the passive margin of the Gondwanan continent beginning in the Late Cambrian, and the Ordovician to Silurian marine sediments reflect the eustatic sea level changes that took place as a result of the Late Ordovician glaciation. Three large scale shallowing upward sequences of clastic marine sediments are exposed in the Al Qassim region. The claystone or shale units represent the maximum flooding horizons, and form the slopes of bluffs and ridges (also referred to as cuestas). These soft sediments are capped by more durable marine sandstones or limestones. The ranks of stratigraphic units mentioned below (Fig. 3) are in accordance with the *Saudi Arabian Code of Stratigraphic Classification and Nomenclature* (Saudi Stratigraphic Committee, 2013).

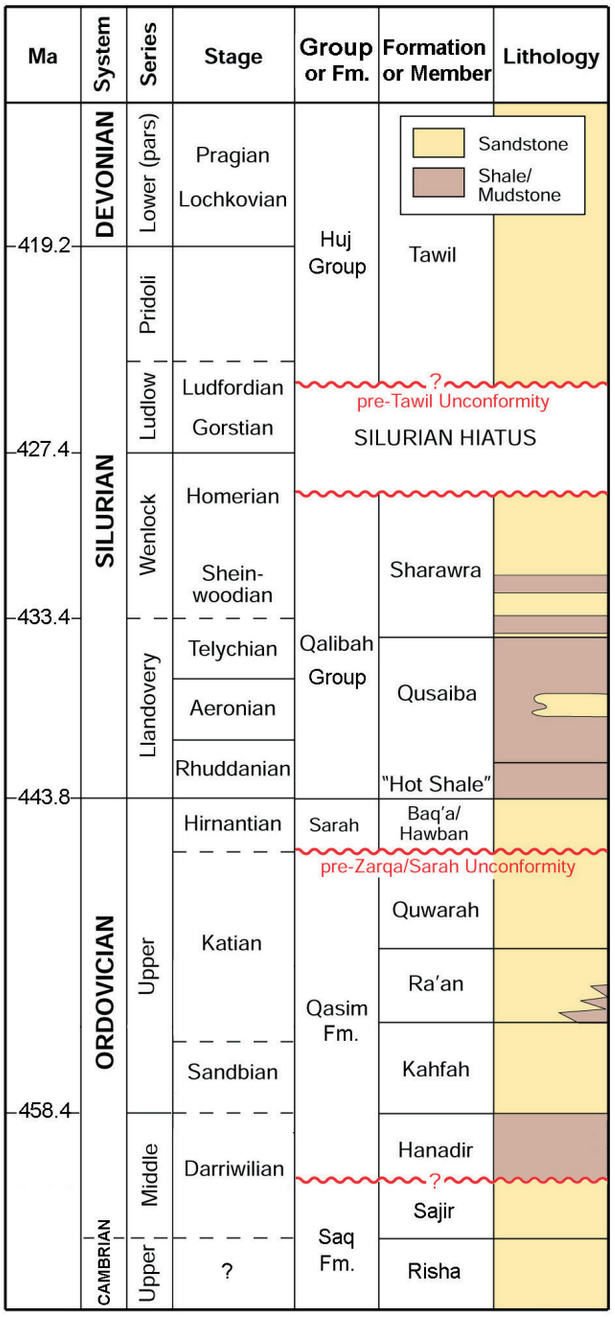

Fig. 3. Lower Paleozoic litho- and chronostratigraphy in the Al-Qassim Province, modified from Zalasiewicz *et al.* (2007). The rank of the lithostratigraphic units is according to the Saudi Stratigraphic Committee (2013)

Geosites

Trip 1: Cambrian to Ordovician

Our first excursion takes us to view the Lower Paleozoic sedimentary rock formations north of Buraydah. The King Abdulaziz Road exits the city and merges into Highway 65 at the intersection with the Western Ring Road on the outskirts of Buraydah (Fig. 1). Traveling in the direction of Hail, the thickly bedded Cambrian sandstone of the Saq Formation is exposed in road cuts along the highway. This area is known for its agricultural products, and the sandstone of the Saq Formation is the local aquifer. At Exit 571, the road signposted

to Tiraq passes a couple of farms on the left-hand side and after 6 km reaches a rubbish dump. Approximately 300 m past the rubbish dump, an unpaved track enters the road on the left, marked by a tractor tyre (26°35.0784'N, 43°23.4332'E). The track descends a slope and enters a broad wadi[1] with a dry playa lakebed (Fig. 4A). On the right-hand side, there is a line of cliffs formed by the dark grey shale of the Hanadir Member of the Qasim Formation. The track branches off to the right at the base of the slope. On the opposite side of the playa lake, the track continues to the highest point along the cliffs. Our destination is at the end of this line of cliffs where an archeological monument (Fig. 4B), a stone inscribed with Thamudic lettering and surrounded by a chain-link fence, is located at the base of the cliff (26°34.3334'N, 43°22.1898'E) (Fig. 4C). The site is known as Al-'Asoudah. Looking toward the west, we observe in the middle distance a gently undulating plain covered with dark slabs of sandstone. The field appears dark because many of the rock slabs are coated with desert varnish.

Location 1a: Cambrian–lower Middle Ordovician Saq Formation (26°34.7468'N, 43°22.6255'E)

Location 1a is one of the most famous localities for trace fossils in the whole of the Middle East. It is here that Denis Vaslet collected specimens of trilobite traces for the famous trace fossil expert Adolf Seilacher (Tübingen) who described the ichnospecies *Phycodes fusiforme* from this locality (Seilacher, 2000). After crossing the pink shale of the lowermost Hanadir Member, we see the disconformity between the Sajir Member of the Saq Formation and the Middle Ordovician Hanadir Member of the Qasim (spelled with one "s") Formation (Fig. 4D). The Sajir Member had been reported to be of Early Ordovician age, based on comparison with similar facies in Jordan (Saudi Stratigraphic Committee, 2013), but recent studies by a team lead by Saudi Aramco paleontologists (Le Hérissé *et al*., 2017) suggest a Middle Ordovician (early Darriwilian) age for the upper part of the sandstone of the Sajir Member. The chitinizoan index species *Siphonochitina formosa* was found in the topmost Sajir Member, constraining the age to late-early Darriwilian. Therefore, the hiatus between the two formations is of short duration, if it exists at all (Marco Vecoli, personal communication, 2020). The upper unit of the sandstone of the Saq Formation (Sajir Member) is marine, and was deposited in a sandy tidal flat environment. The thin-bedded slabs of sandstone exposed at the top of the formation near the unconformity are often ripple-marked and covered with abundant trace fossils created by the activities of trilobites (Fig. 4E). The best localities for trace fossils are the shallow gullies where the occasional rainstorm washes away the sand, exposing slabs of reddish sandstone. It may be necessary to turn the slabs over to reveal the trilobite traces. Most of the traces represent the feeding or foraging activities of arthrophycids (*Phycodes*), but it is also possible to observe locomotory trails (*Cruziana*), and resting traces (*Rusophycus*) of trilobites.

[1] The term "wadi" refers to a dry desert valley formed by an ephemeral stream or river.

Location 1b: Middle Ordovician Hanadir Member (Lower Qasim Formation) (26°34.2658'N, 43°22.0751'E)

Returning to the Al-'Asoudah archeological site at the base of the cliff, we observe a vertical section through the exposed part of the shale of the Hanadir Member. The Hanadir shale forms the basal unit of the Qasim Formation, which is from the Middle Ordovician age. The Hanadir Member is a petroleum source rock in the subsurface, and a recent major discovery in this formation by palynologists at Saudi Aramco (Vecoli *et al*., 2017) has recast what we know about the historical geology of land plants. Vecoli and co-workers (2017) discovered tetrad cryptospores originating from primitive bryophytes (mosses) that had been growing in wet areas along the coastline of the Gondwanan Continent. The occurrence of cryptospores in sediments of Middle Ordovician (Darriwilian) age in Saudi Arabia suggests that the colonization of land by primitive plants first took place in Gondwana. Previously, the earliest land plant fossils were found in the Middle Silurian (Wenlock) in the Czech Republic (Libertín *et al.,* 2015).

Opposite the archeological site, there is a small gully containing large fallen blocks of sandstone. At the head of the gully, we observe a thick lens-shaped sandstone body (Fig. 4F). On the left side of the gully shale of the Hanadir Member is exposed (Fig. 5A), which yields abundant tuning-fork shaped graptolites (*Didymograptus protobifidus* and cf. *bifidus*), as well as the occasional fragment of a trilobite (Fig. 5B). The presence of graptolites belonging to the Didymograptus murchisoni Zone at this locality provides an exact age (middle part of the Darriwilian) for shale of the Hanadir Member.

Location 1c: uppermost Ordovician Sarah Formation

Above the graptolite locality at the head of the gully, there are fallen blocks of amalgamated conglomeritic sandstone. This is the uppermost Ordovician sandstone of the Sarah Formation, which serves as a petroleum reservoir rock in the subsurface. The sandstone forms sinuous elongated sandstone bodies that in places are in contact with the underlying shale of the Hanadir Member, an important hydrocarbon source rock. At this locality, we observe a lens-shaped cross section through one of the sandstone bodies, whose origin reflects an interesting aspect of the latest Ordovician Gondwanan glacial event.

The latest Ordovician (Hirnantian) was a cold period in Earth's history, and a large continental ice sheet formed over parts of the Gondwanan continent. Plate tectonic reconstructions place the South Pole in northwest Africa at the time (Fig. 6), and a continental glacier extended out in all directions, reaching present-day Saudi Arabia (Vaslet, 1990).

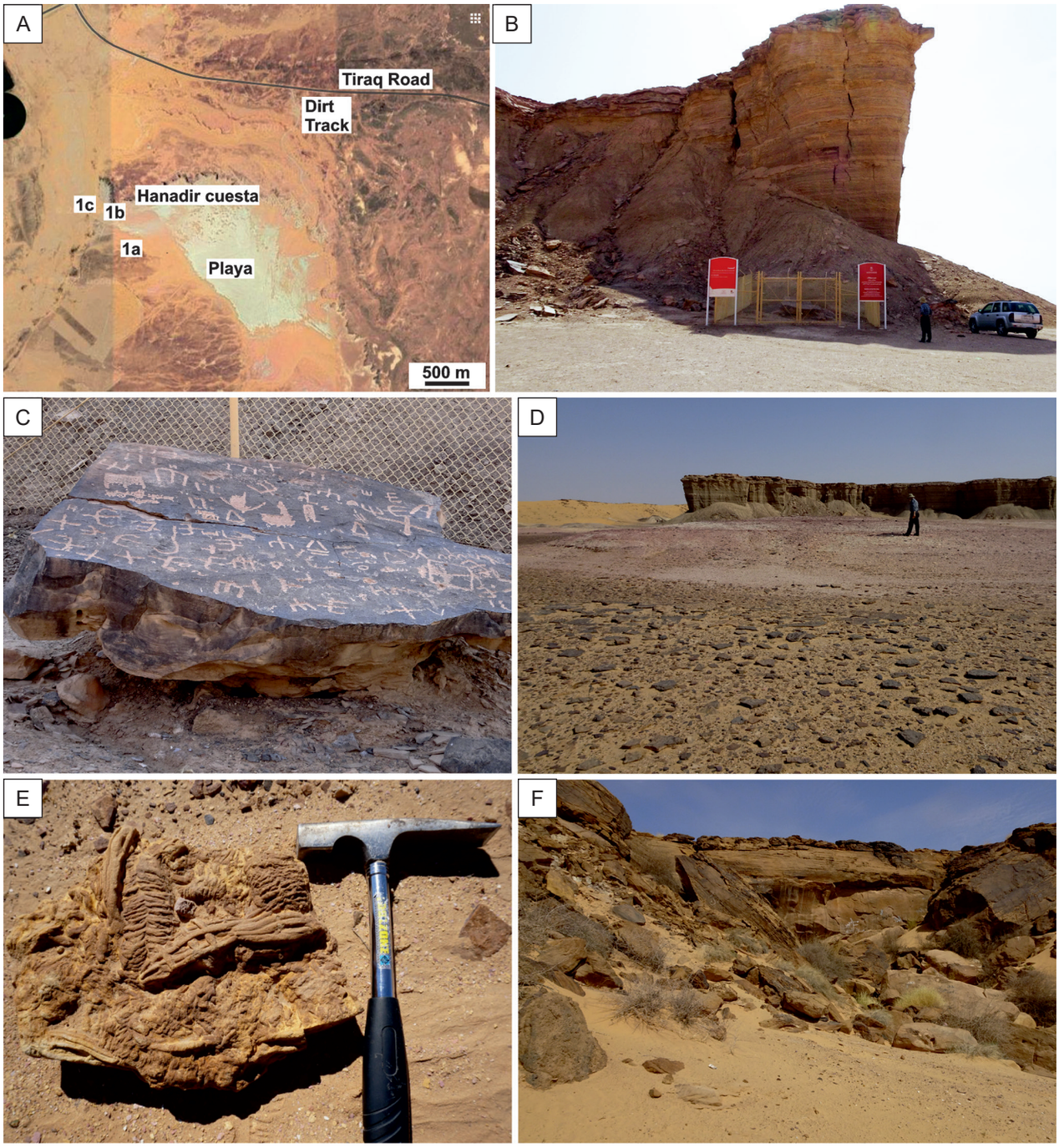

Fig. 4. Geotouristic objects described in the text: A – map of Locality 1; B – archeological site "Al-'Asoudah" at Locality 1; C – the inscribed stone at Locality 1; D – view of the contact between sandstone of the Sajir Member of the Saq Formation and the Middle Ordovician Hanadir Formation at Locality 1a (the slabs of sandstone of the Sajir Formation are in the foreground, and the Hanadir cliffs are in the background); E – trilobite and arthrophycid trace fossils on a slab of sandstone of the Sajir Formation at Locality 1a; F – channelised uppermost Ordovician sandstone of the Sarah Formation in a side gully at Locality 1b. Photos M. Kaminski unless otherwise noted.

At the margins of the melting ice sheet, rivers of melt water flowed out from beneath the ice, similar to glacial rivers that can be seen in modern-day Greenland. The melting Hirnantian ice sheet also had such rivers, which carved their channels into the underlying Ordovician marine sediments, forming structures known as "tunnel valleys". The glacio-marine sandstone of the Sarah Formation contains rounded quartz pebbles derived from the basement rocks of the Arabian Shield (Fig. 5C), and were deposited in these incised tunnel valleys.

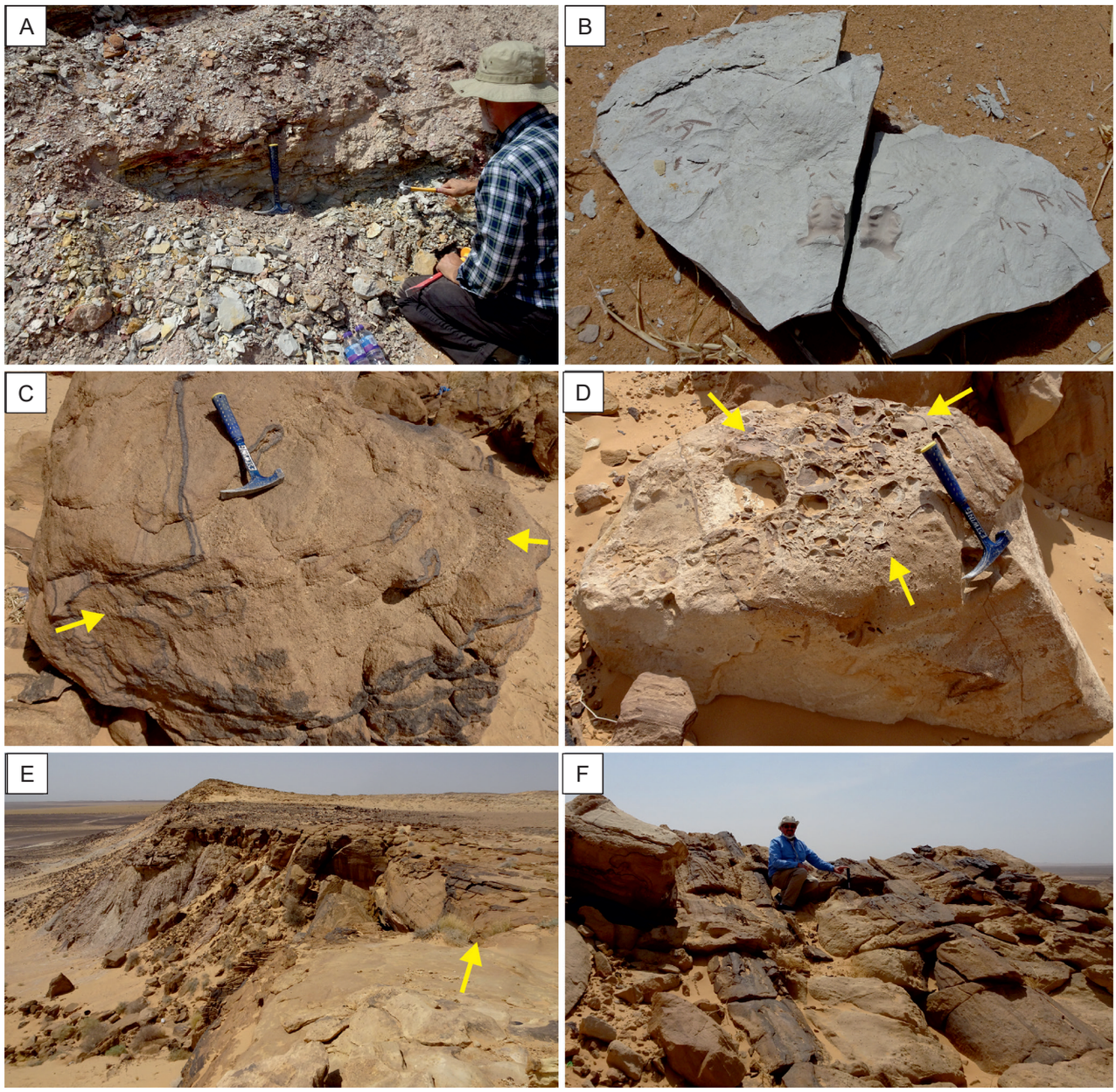

Fig. 5. Geotouristic objects described in the text: A – middle Ordovician shale of the Hanadir Member of the Qasim Formation in a side gully at Locality 1b; B – graptolites and trilobite fragments in shale of the Hanadir Member, Locality 1b; C – boulder of latest Ordovician sandstone of the Sarah Formation showing bands of quartz pebble conglomerate (arrows), Locality 1b; D – boulder of Sarah sandstone showing shale intraclasts (arrows) of the Hanadir Formation, Locality 1c; E – view of the lens-shaped body of sandstone of the Sarah Formation from the top of the cliff (the contact between the grey-coloured sandstone of the Kahfah Formation and sandstone of the Sarah Formation is shown by the arrow), Locality 1c; F – glacial striations and grooves carved by the Gondwanian ice sheet, to the left of the Sarah outcrop at the top of the cliff, Locality 1c. Photo C. Yoder

The sandstone of the Sarah Formation is much coarser grained than the underlying Ordovician marine sandstone. The boulders of sandstone (Sarah Formation) also contain shale intraclasts derived from the underlying shale (Hanadir Member of the Qasim Formation) (Fig. 5D).

A the top of the cliff, the contact between sandstone of the Sarah Formation and the lighter coloured marine sandstones of the Kahfah Member of the Qasim Formation of Late Ordovician age is clearly exposed (Fig. 5E). This is an unconformable contact (an angular unconformity). To the left of the sandstone of the Sarah Formation near the edge of the cliff, we can observe groove marks on the surface of the Ordovician marine sandstone caused by the movement of the Gondwanan ice sheet (Fig. 5F).

Fig. 6. Palaeogeographical reconstruction of Gondwana during the Late Ordovician, showing the position of the South Pole, and the location of the study area (base map from Golonka, 2012)

Location 2: Upper Ordovician Kahfah Member (Qasim Formation)

After visiting sandstones of the Sarah Formation we retrace our route, returning to the Tiraq road. At the top of the Hanadir cliff, the Upper Ordovician (late Sandbian to early Katian age) marine sandstones of the Kahfah Member forms low ledges on the right side of the track. Opposite some farm buildings on the left side of the Tiraq road, there is a small hill about 100 m from the road comprised of the Upper Ordovician sandstone of the Kahfah Member (26°36.1973'N, 43°28.2532'E) (Fig. 7A). This outcrop is known for its trace fossils – *Scolithos*, vertical burrows created by sand worms that live in a very shallow marine environment. Halfway up the hill a sandstone ledge is exposed that is completely bioturbated by the *Scolithos*-producing worms (Fig. 7B). Their circular burrows are highlighted by the differential weathering of the sandstone, with the burrow wall more resistant to erosion.

Location 3: Upper Cambrian Risha Member of the Saq Formation

At the intersection of Highway 65 and Road 6280 leading to Uyun Al Jawa, there is an excellent exposure of the thickly bedded Cambrian Risha Member of the Saq Formation. The Risha member is comprised of white quartz sandstone that was deposited in a non-marine setting, probably by braided streams. The sandstone of the Risha Member is the major aquifer in the Al-Qassim Province. At the end of the exit ramp there is a farm road on the right side of Road 6280. About 200 m further on the right side there is an isolated rock tor surrounded by a fence (26°33.0931'N, 43°35.7012'E). This site is known as Antarah's Rock, after the well-known Arabic writer who used to meet with his beloved in the shade of the rock (Fig. 7C). This is another archeological site that preserves ancient graffiti. The weathered surface of the stone shows honeycomb weathering at different scales, caused by slight differences in the cementation of the sandstone. Another standing stone balanced on a narrow pedestal can be seen about 300 m up the dirt track, again surrounded by a chain-link fence (Fig. 7D). In addition to ancient and modern graffiti, this stone preserves some ancient petroglyphs depicting animals such as the oryx, which were once native to the Al Qassim area.

Location 4: Upper Ordovician (middle Katian) Ra'an Member of the Qasim Formation

Continuing along Highway 65 in the direction of Buraydah, we reach Exit 519 signposted for Qassim University on the northern outskirts of the city. Proceeding on Road 419 in the direction of the University there is a playa salt flat on the right side of the road. At the traffic light at the top of a gentle hill, we turn right onto Road 6260 in the direction of Al Qara'a. There is a small mosque at the corner. About 700 m from the intersection there is a water tower on the left side of the road (26°23.9032'N, 43°46.3663'E). A dirt track to the left of the tower passes through a rocky field that is subdivided into a grid by white property markers, and ends at a shepherd's encampment at the edge of an escarpment. In the wadi below the escarpment and to the right, we see a cliff and some rounded hills made of grey shale with glittering veins of gypsum (26°23.2760'N, 43°45.6174'E). The campus of Qassim University is visible on the horizon. This locality exposes the shale of the Ra'an Member of Late Ordovician (Katian) age. The sandstones at the top of the cliff are those of the Upper Ordovician Quwarah Member of the Qasim Formation (Fig. 7E).

The shale of the Ra'an Member represents the last maximum flooding horizon of the Late Ordovician before the onset of the Hirnantian glacial event. The shale here is silty, and contains stringers of thinly bedded sandstone. The shale has a greenish colour when fresh, and weathers to medium grey. Graptolites, conodonts, and trilobites have been reported from the shale of the Ra'an Member (Williams *et al.,* 1986), but none have yet been reported at this locality (26°23.2435'N, 43°45.6968'E). The foraminiferal assemblages at this locality have been studied by Kaminski *et al.* (2019) and contain some of the oldest known multichambered agglutinated foraminifera belonging to the hormosinid group (the genera *Reophax* and *Subreophax*). The maximum flooding surface is exposed in a ravine near the base of shale of the Ra'an Member (Fig. 7F). From this level, the shale becomes more silty upsection until it grades into the overlying sandstone of the Quwarah Member of the Qasim Formation. The thin-bedded slabs of sandstone that are strewn on the surface of shale of the Ra'an Member are bioturbated, and specimens of the trilobite trails (*Cruziana*) have been observed. The sandstones contain numerous millimetre- to centimetre-size iron concretions.

Fig. 7. Geotouristic objects described in the text: A – view of the hill of sandstone of the Kahfah Formation at Locality 2, photo taken from the roadside; B – top view of *Scolithos* trace fossils in sandstone of the Kahfah Formation at Locality 2; C – the tor of sandstone of the Saq Formation known as Antarah's Rock at Locality 3 (the surface of the stone displays honeycomb weathering at various scales); D – the tor balanced on a pedestal at Locality 3; E – view of shale of the Ra'an Formation exposure behind Qassim University, Locality 4; F – the O40 maximum flooding surface within shale of the Ra'an Formation at Locality 4 (arrow). Photo T. Garrison

Trip 2: Silurian to Permian

This excursion begins at exit 571 on Highway 65, but this time we turn right onto Road 6280 at the end of the exit ramp in the direction of Quararah. We cross over the new Saudi railroad and enter the town of Quararah, passing the park along the right side of the road and the town center, and continuing to the large roundabout at the bottom of the hill. Just beyond the roundabout there is a rock formation known as the "Saudi Sphynx" (Location 5), made of reddish thickly-bedded sandstone of the Sarah Formation (Fig. 8A). From the roundabout the Qusaiba road passes some farms until it descends through a road cut. At the base of the hill a smaller road enters the Qusaiba Road on the left (Fig. 8B). A line of cliffs rises up on the left side of the side road exposing dark grey shale. This is the Silurian Qusaiba Formation, the most prolific petroleum-producing unit in the Middle East. The whole Paleozoic petroleum system in the Gulf countries is fuelled by hydrocarbons produced from shale of the Qusaiba Formation.

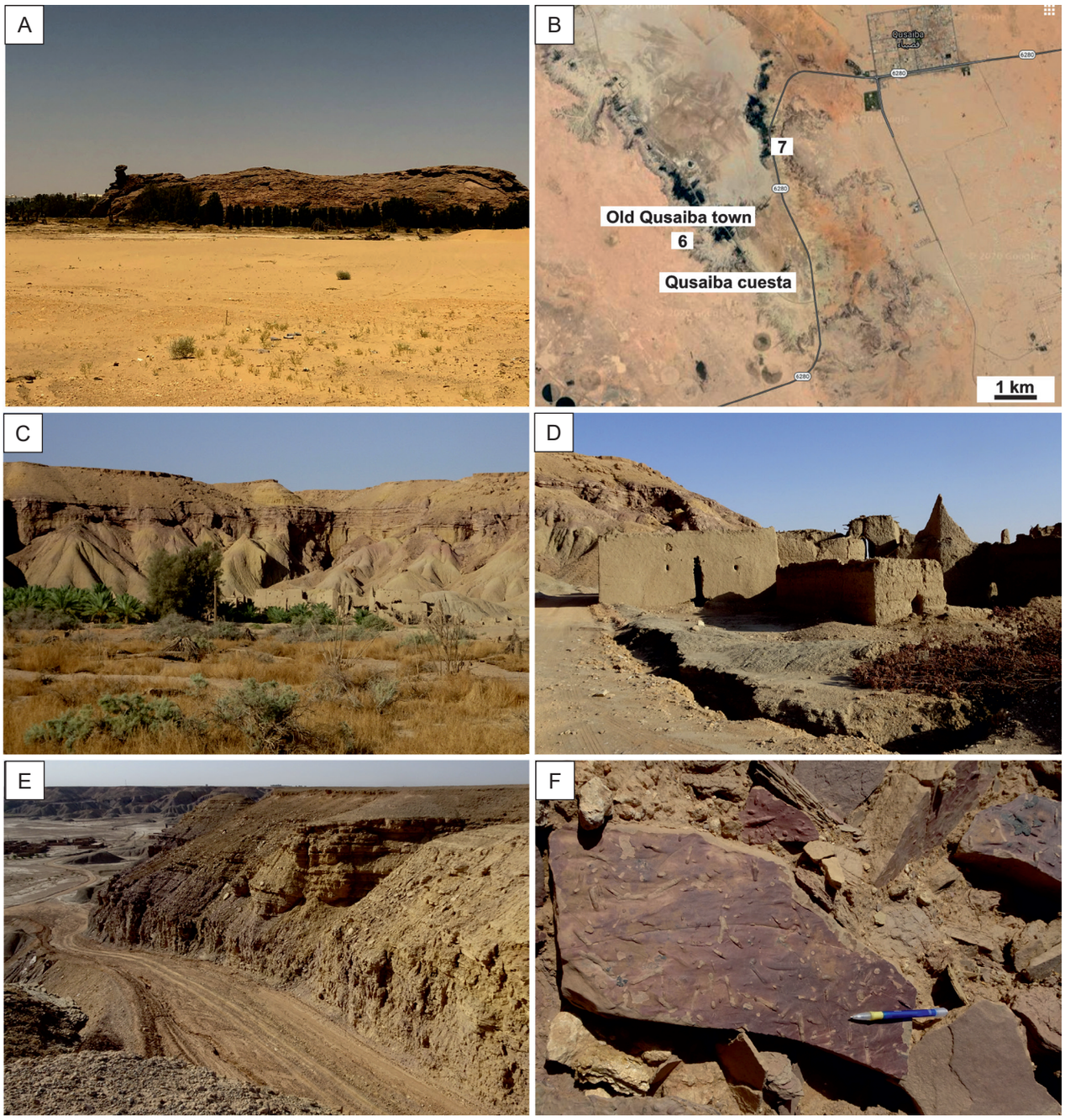

Fig. 8. Geotouristic objects described in the text: A – view of the "Saudi Sphynx", a hill comprised of sandstone of the Sarah Formation in Quwarah town, Locality 5. Photo T. Garrison; B – map showing the position of Localities 6 and 7; C – Old Qusaiba Village with the exposure of shale of the Qusaiba Formation and sandstone of the Sharawra Formation in the background. View from the main road at Locality 6; D – some of the surviving mud-brick structures in Old Qusaiba Village; E– the section of shale of the Qusaiba Formation and sandstone of the Sharawra Formation sampled by Abbas *et al*. (2017) and by Kaminski & Perdana (2017, 2020), viewed from above; F – trace fossils on the upper surfaces of sandstone of the Sharawra Formation, road cut overlooking Old Qusaiba Village

After passing the large date farm enclosed by a cinder block wall, a dirt track on the left leads to the base of the cliff (26°49.8281'N, 43°36.7686'E). A second road branches off to the right and follows the base of the cliff to the abandoned Old Qusaiba village (26°50.8585'N, 43°35.1025'E), a picturesque archeological site consisting of ruins of mud brick structures (Figs. 8C, D). We return along the same road, pass the junction, and proceed along the base of the cuesta several hundred meters to a dirt track that ascends the cliff (Fig. 8E) (26°50.6381'N, 43°35.2163'E).

Location 6: Lower Silurian shale of the Qusaiba Formation

At Old Qusaiba village, only the upper half of the Qusaiba Formation is exposed. The lower half is covered by talus all along the base of the cliff. A borehole drilled by Saudi Aramco on top of the cliff recovered a thickness of 32 meters of shale of the Qusaiba Formation at this locality. Graptolites from the Qusaiba-1 core were studied by Zalasiewicz *et al*. (2007), who found assemblages belonging to the Lituigraptus convolutus graptolite Zone of Aeronian age. A total of 14 graptolite species were reported at this locality, mostly the monograptids such as *Lituigraptus*, *Normalograptus*, *Pseudorthograptus* and *Neolagerograptus*, but also including occasional phyllograptids such as *Petalolithus*. The low diversity of the graptolite assemblage points to a continental shelf environment (Zalasiewicz *et al*., 2007), probably mid-shelf, below the wave base. The early Silurian foraminifera from this locality were studied by Kaminski & Perdana (2017, 2020), who reported a diverse assemblage consisting almost entirely of primitive agglutinated foraminifera belonging to the monothalamid and tubothalamid groups. Unexpectedly, Kaminski & Perdana (2017) also discovered some rare specimens of coiled multichambered lituolids, including the oldest known species belonging to the genus *Ammobaculites*. This finding represents the oldest known occurrence of multichambered foraminifera belonging to the lituolid group, and pushes back the known geological history of the coiled multichambered foraminifera by about 40 million years. Previously, the oldest known *Ammobaculites* was reported from the Lower Devonian in the Czech Rebuplic (Holcová, 2002).

The lower part of the Qusaiba Formation found in the subsurface contains the organic-rich "hot shale", which was deposited in anoxic conditions that took hold in the ocean after the melting of the Gondwanan ice sheet (Hayton *et al*., 2017). During the early Silurian, black graptolite-bearing shales were deposited world-wide (Lüning *et al*., 2000).

Along the dirt track that leads to the top of the cliff above Old Qusaiba village, we see the transition to the overlying Sharawra Formation, which is comprised of fine to medium grained subarkosic sandstones interbedded with green claystones (Abbas *et al.*, 2017). Although fine silt layers can be seen in the upper part of shale of the Qusaiba Formation, the boundary with the overlying Sharawra Formation is placed at the lowermost sandstone bed. Thin-bedded sandstones at the base of the formation are micaceous and their upper surfaces display trace fossils created by benthic organisms (Fig. 8F). The thickness and frequency of the sandstone beds increases upsection. The Sharawra Formation was deposited in a lower to upper shoreface environment, with sediment sourced from the Arabian Shield. The maximum thickness of the Sharawra Formation at this locality is 27 m, and the unit thins in the SW direction (Abbas *et al*., 2017). The top of the outcrop is capped by a hard layer of calcareous duricrust. Along the edge of the cliff overlooking the Old Qusaiba village, a series of stone watch towers was constructed by the inhabitants of the village in pre-modern times. Ruins of the watch towers can still be seen near the edge of the cliff (Fig. 8A).

Location 7–8: Middle Permian Unayzah Formation

The next locality is along Route 6280 that leads in the direction of the modern Qusaiba township. On the right hand side, we see a cliff comprised of variegated clastic sediments capped by limestone of the Permian Khuff Formation. A dry streambed passes beneath a bridge just before the road curves to the right and ascends to Qusaiba (26°52.2539'N, 43°36.2227'E). We walk upstream until we reach a tributary stream that cuts exposes a red cross-bedded sandstone (Fig. 9B). These are the nonmarine sandstones of the Unayzah Formation, which is also known as the "pre-Khuff clastics" by Saudi Aramco geologists. The unit was formally named the Unayzah Formation by Al-Laboun (1987) and is assigned a middle Permian (Wordian) age based on the occurrence of fossil plants (Lemoigne, 1981; El-Khayal, Wagner, 1985). Pre-Khuff clastic sediments of late Carboniferous to early Permian age are well developed in the subsurface and are subdivided into three informal units by industry geologists.

The sandstone is rippled and cross bedded at a large scale. It forms lenticular bodies, and was likely deposited by a major river. The sandstone at this locality contains large silicified logs of petrified wood that erode out of the sandstone (Fig. 9C). Pieces of petrified wood can be seen among the gravel in the modern-day streambed. Several streams cut through the Unayzah Formation at this locality.

It is possible to return to Buraydah on Route 400, via New Qusaiba town. On the outskirts of Buraydah the road passes a complex of grain silos on the left-hand side of the road, and descends down a line of low cliffs. This cliff again exposes limestone of the Khuff Formation and the underlying clastics of the Unayzah Formation. Location 8 is a protected geological site that was preserved thanks to the efforts of Dr. Abdulaziz Al-Laboun of King Saud University, who worked on the Unayzah Formation in the area (26°26.4929'N, 43°50.2104'E). Enclosed within a chain-link fence on the left-hand side of the road is a large log of petrified wood (Fig. 9D). It is possible to walk along the base of the cliff in the direction of Buraydah and observe fragments of petrified wood that erode out of the formation.

Cultural sites

For centuries, the Al-Qassim area has been a stopover point for pilgrims travelling to Mecca and Medina. The historical sites in the Al-Qassim region provide an idea of what life was like in a desert oasis in pre-modern times. The petroglyphs preserved on stones indicate that the region has been inhabited since Pre-Islamic times.

Fig. 9. Geotouristic and touristic objects described in the text: A – ruins of a watch tower on top of the bluff overlooking Old Qusaiba village; B – cross-bedded red sandstone of the Unayzah Formation at Locality 7. Photo T. Garrison; C – logs of petrified wood eroding out from the Unayzah at Locality 7. Photo T. Garrison; D – large logs of petrified wood (arrows) in sandstone of the Unayzah Formation at Locality 8. Photo T. Garrison; E – the landmark "golf ball" in the centre of Buraydah, near the convention centre; F – view of the gold market in the souq in Buraydah

Modern-day Buraydah is a rapidly developing regional center with modern facilities, including tourist hotels and many of the well-known chain restaurants. The King Khalid Cultural Center, King Khalid Park, and Buraydah Museum are tourist attractions within walking distance of each other. Also nearby is the Buraydah Water Tower, which is a popular landmark that dominates the local skyline (Fig. 9E). The older downtown district is famous for the Buraydah Date Market and for its souq. The modern souq contains numerous stalls offering items of jewellery fashioned from Saudi gold (Fig. 9F). Another section of the downtown souq contains the spice market, which is well worth an aromatic visit.

Discussion

Geotourism value

The Paleozoic succession of the Al-Qassim Province has educational value to petroleum geologists interested in the subsurface petroleum system of the Middle East. The outcrops north of Buraydah expose the most important source rocks in Saudi Arabia, as well as some of the subsurface reservoirs. The sandstone of the Sarah Formation has been a target for hydrocarbon exploration in the subsurface in the Rub Al-Khali desert of southern Saudi Arabia. The carbonates of the Khuff Formation are the major gas producer in the world's largest natural gas field in Qatar, and the Unayzah clastics are another reservoir unit in Saudi Arabia. Palaeontologists will be impressed with the trace fossils of the Sajir sandstones, and specialists will be interested in the remains of the oldest microfossils derived from land plants in shale of the Hanadir Member of the Qasim Formation. The Ra'an shale near Qassim University and the Qusaiba shale in Old Qusaiba town contain a diverse assemblage of agglutinated foraminifera that includes some of the oldest known multichambered forms. These discoveries are so important that textbooks will need to be revised based on the recent micropalaeontological and palynological studies.

Geotourism infrastructure

Buraydah is a modern city with all the necessary infrastructure to support geotourism. The city has a wide selection of chain hotels and restaurants. Prince Nayef bin Abdulaziz International Airport (formerly known as the Qassim International Airport) is served by a number of Middle Eastern airlines and has regular connections to all of the major airport hubs in the region. The recently built train line offers passenger service to the capital city Riyadh, with onward connections to Dammam. The city of Buraydah, with its abundant tourist attractions and infrastructure, ranks highly using the geotourism valorisation criteria adopted by Doktor *et al*. (2015).

The Saudi Commission for Tourism and National Heritage is in the process of developing Qusiaba as a geotourist destination (Saudi Gazette, 2018). However, the geological localities described above currently do not have tourism infrastructure, explanatory signs, or tourist information brochures. A 4-wheel drive vehicle is recommended to access some of the localities. Fortunately, the outcrops are well-exposed, and the local structural geology is quite simple. There are small grocery shops and petrol stations in Al Quwarah and Qusaiba where basic items such as cold drinks can be purchased, but the geotourist is advised to pack ample supplies of drinking water. Daytime temperatures during summer months regularly exceed 45ºC, and it is best to visit the localities early in the morning before the temperature becomes uncomfortable. Furthermore, the geotourist will be exposed to the open sun the entire time and is strongly advised to take all necessary precautions for sun protection.

Finally, a visit to Al-Qassim is genuinely a rewarding experience because of the exposure to traditional Saudi culture through date farming, shopping at the souq, and the wonderful Saudi cuisine that can be sampled at traditional restaurants.

Conclusions

Al-Qassim district of Saudi Arabia has strong potential for geotourism. There are excellent geological sites that are well exposed and easily accessed. Furthermore, the Paleozoic formations are among the most important geological units in terms of natural resources, which drive the economy of the Middle East. Their educational value to geoscience students and specialists ranks highly because they contain unique fossil and microfossil occurrences that give us a new perspective on the evolution of land plants and marine microorganisms on our planet. Furthermore, the stratigraphic units exposed in the Al-Qassim district can be used to explain the history of the Gondwanan continental shelf that includes the latest Ordovician glacial event.

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