Early Carboniferous (Mississippian) miospore assemblage from Persian Gulf, Southwest Iran

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Abstract
A Mississippian miospore assemblage has been recorded from well A in the Persian Gulf in Iranian offshore, for the first time. Fifteen species of spores have been recognized in the Early Carboniferous assemblage of this well which the most important of them are: Spelaeotriletes arenaceus, Aratrisporites saharaensis, Spelaeotriletes balteatus, Spelaeotriletes triangulus and Radiizonates arcuatus. Comparing this assemblage with their coevals from the North Africa, Middle East, Western Australia and South America reveals a very close similarity indicating the Gondwanic nature of the assemblage. Also, the Carboniferous strata in this area can be correlated with the Berwath Formation in Saudi Arabia. Based on the palynological data two hiatuses have been recognized at the base and top of the Carboniferous strata.

Keywords: Carboniferous; Mississippian; Gondwana; Miospore; Persian Gulf.

Introduction
The exploratory borehole A, located in the Iranian offshore of Persian Gulf, drilled by the National Iranian Oil Company (NIOC) in 2014 (Fig. 1). Although, the Carboniferous strata are not well known in Zagros and are limited only to a few boreholes in the Southwest of the Zagros fold and thrust belt (Sabouri et al., 2014). They are well known and described from the neighboring Saudi Arabia (Clayton, 1995; Clayton et al., 2000). Therefore, it is important to search and report these rock units due to their paleogeographical position.

The Carboniferous deposits of the Central, Northern and Southwestern Iran have previously been investigated palynologically by Ghavidel–Syooki & Owens (2007), Sabouri et al. (2014), Aria–Nasab et al. (2016), Sabbaghiyan & Aria–Nasab (2016), Sabbaghiyan (2011; 2016). The first report on the miospore assemblages from the Carboniferous of Southwest Iran (Zagros fold and thrust belt) published by Sabouri et al. (2014). They examined cuttings of three boreholes in Fars area and assigned Visean–?early Serpukhovian age to the strata.

Materials and methods
Fourty cutting samples of dark colored, shaly sandstones and shales were collected from well A and prepared in the palynology laboratory of the National Iranian Oil Company (NIOC) for their palynomorph contents. Of these, 16 samples were productive and yielded miospores. Each sample was washed by running water to remove drilling mud and 30 grams of each sample were prepared by the method of Traverse (2007). Cold hydrochloric (10%) and hydrofluoric (40%) acids were used to dissolve carbonates and silicates. The residue was neutralized and centrifuged in ZnCl2 (specific gravity 1.9), then sieved with a 15 μm nylon mesh and mounted on microscopic slides using liquid Canada balsam. Two slides were made from each sample. The microscope slides were examined with an optical microscope and the index spore species were photographed and presented in Plates 1–2. All slides are housed at the Palynology laboratory of the National Iranian Oil Company.

Lithostratigraphy
Carboniferous deposits in well A are 82 m thick and composed of alternations of sandy claystone and sandy shale interbedded with thin bedded sandstone (Fig. 2). These strata here unconformably overlie the Zakeen Formation (Upper Devonian) and are overlain unconformably (an evidence of Hercynian Unconformity) by the Faraghan Formation recently attributed by Spina et al. (2018) to the Middle Permian. From lithological point of view, the Carboniferous rock unit in this well can be separated easily from the lower and upper rock units (Fig. 3).

Palynology and palynostratigraphy
In most of the investigated productive slides,
miospores are relatively abundant, diverse and well preserved. *Aratrisporites saharaensis*, *Calamospora liquida*, *Cingulizonates bialatus*, *Cyclogranisporites firmus*, *Densosporites spitsbergensis*, *Densosporites anulatus*, *Grandispora maculosa*, *Indotriradites daemonii*, *Radiizonates arcuatus*, *Vallatisporites vallatus*, *Tricidarispores serratus*, *Spelaeotriletes arenaceus*, *Spelaeotriletes balteatus*, *Spelaeotriletes triangulus* and *Spelaeotriletes sp.* are the main palynomorphs recorded.

Figure 1. Location map of the studied well.

Figure 2. Distribution chart of the selected miospores in well A.
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Most of these species have been reported from other parts of Gondwana such as Saudi Arabia (Clayton, 1995; Clayton et al., 2000), Australia (Playford & Mory, 2017), Niger (Coquel et al., 1995), Algeria (Coquel & Abdesselam–Rouighi, 2000), Libya (Massa et al., 1980; Loboziak & Clayton, 1988), Morocco (Playford et al., 2008) and Brazil (Melo & Loboziak, 2000).

Aratrisporites saharaensis is palaeogeographically a characteristic element of the Early Carboniferous North African "Aratrisporites saharaensis Microflora" (Clayton, 1985; Clayton, 1991) (Fig. 4). This species is known from late Visean deposits of Northern, Eastern and Western Gondwana (Clayton, 1995; Clayton et al., 2000; Coquel & Abdesselam–Rouighi, 2000; Playford & Mory, 2017; Melo & Loboziak, 2000).

The species has also been reported from Early Carboniferous (late Tournaisian) deposits of Central Iran (Sabbaghiyan & Aria–Nasab, 2016; Aria–Nasab et al., 2016; Sabbaghiyan, 2016) and Brazil (Playford et al., 2012; Loboziak et al., 1998).

The presence of this index spore in well A can show the relation between Iran and Gondwanan realm during this period of time.

In Northern Gondwana region Spelaeotriletes arenaceus has been recognized from late Visean strata (Playford et al., 2008; Coquel & Abdesselam–Rouighi, 2000; Clayton et al., 2000; Coquel et al., 1995).

Densosporites anulatus has been recorded from the Tournaisian–Moscovian age, in Ambo Formation in Peru (Azcuy & di Pasquo, 2005).
Spelaeotriletes triangulus is important zonal species of the late Visean to early Serpukhovian. In northeast Libya and the base of the RT biozone is defined on the first appearances of this species and Prolycospora rugulosa (Clayton et al., 2000; Loboziak & Clayton, 1988). Aratrisporites saharaensis, Cingulizonates bialatus, Densosporites spitsbergensis, Indotriradites dolianitii, Radiizonates arcuatus, Spelaeotriletes arenaceus and Spelaeotriletes triangulus have been reported from Visean deposit in Parnaba Basin, Northern Brazil (Melo & Loboziak, 2000).

Miospores as Aratrisporites saharaensis, Cyclogranisporites firmus, Grandispora maculosa and Indotriradites daemontii have been recorded from middle to late Visean Grandispora maculosa biozone of Western Australia (Playford & Mory, 2017).

Spelaeotriletes balteatus has been recorded from Tournaisian age within the Spelaeotriletes balteatus–Rugospora polyptycha (BP) and Spelaeotriletes pretiosus–Raistrickia clavata (PC).
biozones of Ireland (Brittain & Higgs, 2007) and Belgium (Higgs, 1996).

Several specimens of Retispora lepidophyta were recorded as reworked. Also this species has been recorded as reworked miospore in Carboniferous sediment in Saudi Arabia (Clayton, 1995; Clayton et al., 2000; Owens et al., 2000), Northeastern Brazil (Playford et al., 2012) and Australia (Playford & Mory, 2017).

The palynoflora of the Carboniferous strata in well A show a close similarity to the Early Carboniferous palynofloras reported from other parts of Gondwanan regions indicating the Early Carboniferous (late Tournaisian–late Visean) age for this assemblage.

**Discussion**

The Carboniferous deposits of Saudi Arabia are represented by the Berwath Formation and only identified in subsurface sections (Powers, 1968).

The type locality of the Berwath Formation is situated in well ST–8 in northern Saudia Arabia. In South of the Persian Gulf, the Berwath Formation has been recorded in wells 1, 2, 4–6 (Craigie et al., 2016) and Abu Safah–29 well (Clayton, 1995; Clayton et al., 2000) with late Tournaisian–early Serpukhovian age.

Clayton (1995) and Clayton et al. (2000) identified the Carboniferous miospores of three wells in Saudi Arabia. In Arabian side of Persian Gulf, Clayton et al. (2000) reported several miospore species such as Aratrisporites saharaensis, Spelaeotriletes triangulus, Radizonates genuinus, polyospora rugulosa and Spelaeotriletes arenaceus with late Visean age from upper part of Berwath Formation in Abu Safah–29 well. Also, Hooker et al. (2011) reported two biozone (C4–C5) with late Tournaisian–late Visean age from Berwath Formation in Saudi Arabia.

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**Figure 3.** Lithostratigraphic comparison between the Carboniferous deposits of well A in southwest Iran with Berwath Formation of Abu Safah–29 (Gamma ray after Craigie et al., 2016; Lithology redrawn from Clayton et al., 2000) in Saudi Arabia.
Miospore assemblage of well A can be correlated to these two Biozones. For the first time in this study, Carboniferous deposits were identified in Iranian side of Persian Gulf. The recognized Early Carboniferous assemblage of this well dominantly contains *Spelaeotriletes arenaceus* and *Aratrisporites saharaensis*. Also the index species of Visean such as *Cingulizonates bialatus* and *Grandispora maculosa* are present in this assemblage.

However, all of these miospores more or less are quite similar to those of the Gondwanan realm. Also, the examined strata in well A are similar in fossil content and lithology to Berwath Formation of Saudi Arabia. The Carboniferous deposits in Iranian side of Persian Gulf (well A) are compared with their coeval deposits (Fig. 3) mainly from Arabian side of Persian Gulf (Abu Safah–29). The palynological evidence indicates the disconformity between Zakeen and Carboniferous deposits in this well can be assigned to the period of erosion because the latest Devonian index miospores (e.g. *Retispora lepidophyta*) appear as reworked specimen in carboniferous strata.

**Conclusions**

Moderate diversity and well–preserved palynofloras have been recorded from Early Carboniferous strata in well A of the Persian Gulf Southwest Iran that dominated by miospores. Based on the stratigraphic value of the recognized miospore taxa and comparison with other parts of the Gondwana a late Tournaisian–late Visean age attributed to the assemblage. Biostratigraphical data indicate two hiatuses in the base and top of the Carboniferous strata. The late Tournaisian–late Visean assemblage from well A in Southwest Iran is very similar to coeval Gondwanan assemblage (Algeria, Saudi Arabia, Libya, Morocco, north Brazil, Australia, Central and North Iran). Also, the examined Carboniferous strata in well A are lithologically similar to the Berwath Formation of Saudi Arabia and they are differentiated from the overlying (Faraghan) and underlying (Zakeen) deposits.

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**References**


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