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Multiple Stratigraphy Study of the Ordovicianin SW Ordos, China

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The Ordovician (485.4 Ma-443.8Ma) is the longest period of the Paleozoic, which was characterized by a peak of greenhouse climate in Earth history, as well as extreme high sea level (Haq and Schutter, 2008; Munnecke et al., 2010), with warm and humid conditions in early-middle period and seawater temperature up to 45°C (Trotter et al., 2008). The carbon cycle fluctuated greatly (Melchin et al., 2013; Cramer et al., 2015) and atmospheric CO_2 concentrations reached ~4200 ppm. During the Late Ordovician, severe glacial conditions developed and the Earth entered its second Snowball Earth period (Nardin et al., 2011). The Ordovician also shows a great development of marine life,which spread heavily after the Cambrian.Biologic genera and families (Dixon et al., 2001; Webby et al., 2004; Harper, 2006) andhard shell organisms rapidly increased (Wilson and Palmer, 2006). More importantly, mosses (Redecker et al., 2000) began to ascend on the mainland during the Ordovician, and animals such as fish, corals, and cephalopods began to appear in the Ordovician. At the end of the Ordovician period a major extinction event decimated more than 60% of marine invertebrates and was the second largest after the Permian-Triassic extinction.

Due to the lack of accurate high-resolution geologictime scale, there are still many controversies about the time and mechanism of these climate and biological evolution events (Melott et al., 2004; Trotter et al., 2008; Harper et al., 2015; Algeo et al., 2016; Rasmussen et al., 2016; Edwards et al., 2017; Lindskog et al., 2017; Stigall, 2017). Therefore, it is very urgent to reach an accurate high resolution Ordovician geologic timescale, through radiogenic geochronologic data, magnetostratigraphy, chemostratigraphy and cyclostratigraphy. In this goal, the collaboration of multiple disciplinary researchers on a global scale is a very important approach. The IGCP-652 project, which includes about 250 researchers from more than 40 countries, aims to improve the geologic time scale of the Ordovician to the Devonian. It is entitled "Reading geologic time in Paleozoic sedimentary rocks: the need for an integrated stratigraphy", and the implementation period is5 years (2017-2021). Using the stratigraphic, geophysical, geochemical and astronomical dating method to studyOrdovician- Devonian sedimentary sections, the project intends to improve the Paleozoic geological time scales. The Chinese workgroup, including more 20 researchers from 7 institutes, is responsible to carry out high-precision geologic timescale studies on the Ordovician from western Ordos Basinin China.

The southwestern Ordos is one of the most developed, well exposed, and highly studied areas of Ordovician in the north of China. During the Ordovician period, the area was located in the low latitudes of the Southern Hemisphere (Yang et al., 1998; Torsvik et al., 2012; Wang et al., 2015), at the transition of southern margin of North China continent and the Qinling-Qilian trough (Feng et al., 1991). The sedimentary environment was a carbonate platform-Platform front slope (Feng et al., 1991; Li et al., 2012). In this contribution, we compile the literature of stratigraphy study for the Ordovician and present our primary data, to form an insight of the Ordovician geologic timescale in southwestern Ordos.

The Ordovician stratigraphy in the southwestern Ordos has been divided into five formations from bottom to top, Yeli, Liangjiashan, Majiagou, Pingliang and Beiguoshan formations, with a total thickness of 1046-2500 meters (Chen, 2010). The Lower Ordovician (Yeli and Liangjiashan Formations) consists of argillaceous dolomite and dolomite, with siliceous bands in the Liangjiashan Formation. The Middle Ordovician(Majiagou Formation)is composed of the laminated argillaceous dolomite and limestone, and massive limestone. It was divided into two parts and each part consists of three members. The Upper Ordovician Pingliang Formation consists of shale, mudstone, sandstone and marl, with some layers of tuff and gravity flow deposit, rich in graptolite. Above Pingliang Formation, the Beiguoshan Formationis composed of the medium- to thick-bedded limestones, intercalated with shale and conglomeratic limestone.

Biostratigraphy studies have shown that the strata contain a large number of trilobites, graptolites, cephalopods (Anand

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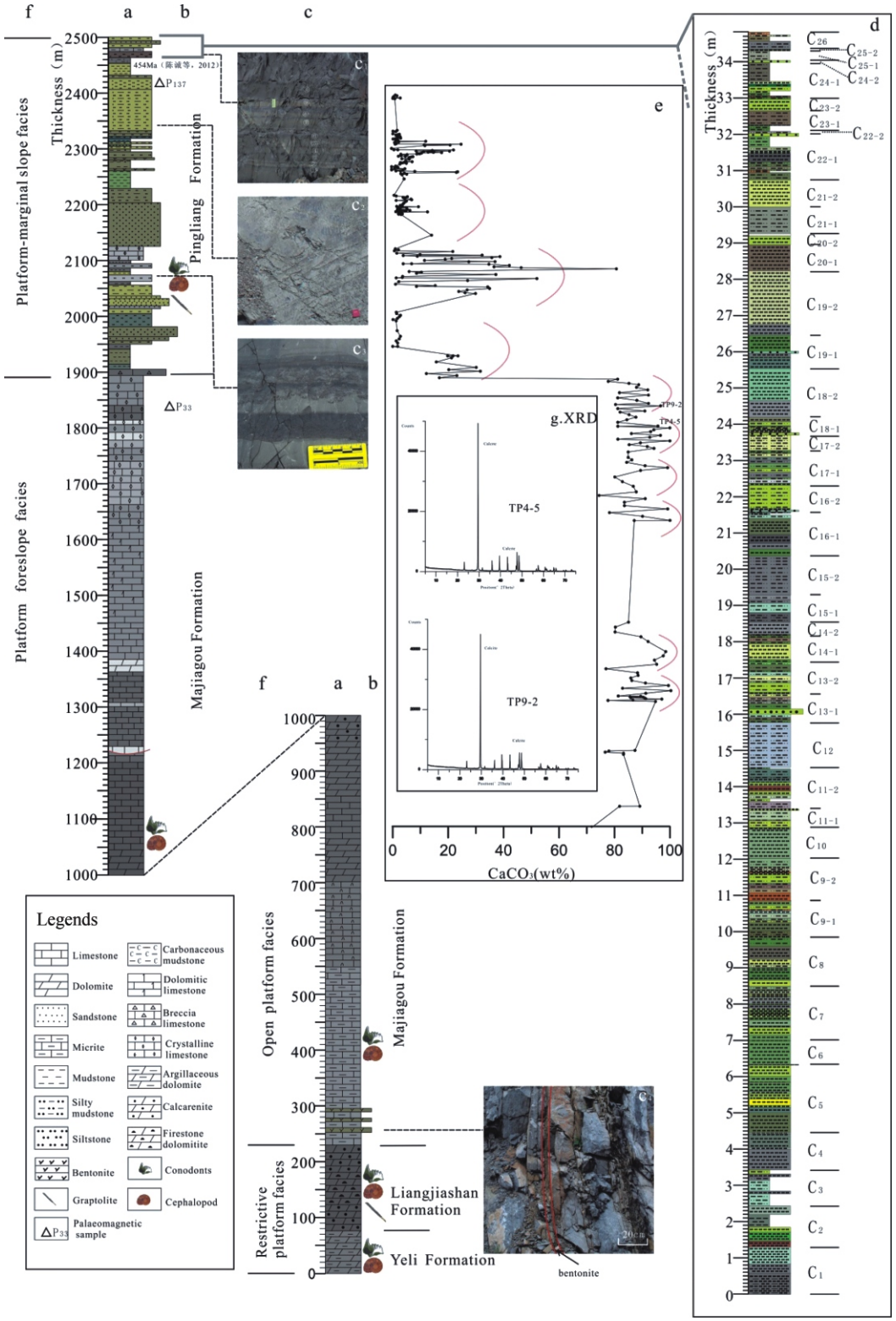

Fig. 1. Composite section showing stratigraphy and lithology (a, c) fossils (b) sedimentary cycles (d) CaCO3 (wt%, e) and sedimentary facies (f) of the Ordovician strata on the Qishan section, southwest Ordos (China).

Zheng, 1990; Mu, 2002; Wang et al., 2011; Wang et al., 2013; Chen, 2015). A graptolite and conodont biostratigraphy, which can be correlated to the global standard biozone, has been established (An and Zheng, 1990; Zhao et al.,2015). The Yeli Formation contains conodont zones of *M. sevierensis*, *R. manitouensis*, *S. opimus*, and *S. tersus*. The Liangjiashan Formation contains conodont zones of *Serra. Bilobatus* and *Serra. extensus*. The Lower Majiagou formation contains conodont zones of *S. eburnus, L. dissectus* and *A. leptosomatus*. The Upper Majiagou Formation contains conodont zones of

S.eburnus, L. dissectus, A. leptosomatus, P. parallelus, S. euspinus, P. originalis, S. rectus, L. variabilis, E.suesicus and *P. serra* and graptolite zones of *A. confetus* and *P. elegans*. The Upper Ordovician Pingliang Formation contains graptolite zones of *H. teretiusculus, N. gracilis, C. bicornis* and *A. gansuensis*. The Beiguoshan Formation contains conodont zones of *P. undatus, Y. neimengguensis, B. confluens* and *P. insculptus*.

Chronostratigraphy study addressed zircon U-Pb dating for the tuff layers within the Pingliang Formation. Some dispersive data obtained in some sections,i.e. 457Ma±3Ma – 449Ma±3Ma at the Pingliang section (Pingliang City, Gansu) and Xilinggou section (Jingyang county,Shaanxi) (Wang et al., 2015), 465.8Ma±8.3Ma-451.5Ma±4.9Ma at the Xilinggou (Jingyang county,Shaanxi) (Chen et al., 2012; Yang et al., 2015), and a peak age of 454 Ma at the Qishan section (Qishan county, Shaanxi) (Yang et al., 2015). These data reassigned the Pingliang Formation as a Late Ordovicianin age. However, these results are not accurate since the errors are between 4 Ma and 8.3 Ma. Subsequently, the calculated accumulation rate is 0.3cm/kyr for the stratigraphic interval between these tuff layers. According to this accumulation rate, the duration of the Pingliang Formation of Pingliang section (ca. 116 meters thick) reaches to 44 Myr. It is obviously unreasonable. Zhao et al. (2015) synthesized the data of paleontological fossil zones, event stratigraphy, sequence stratigraphy and chemostratigraphy to propose a chronostratigraphic model to the Ordovician strata in Ordos. From the bottom to top, the formations respectively assigned to: the Yeli Formation and Liangjiashan Formation to Tremadocian, the Lower Majiagou Formation (traditionally first to third members) to Floian, the Upper Majiagou Formation (fourth-sixth members) to Dapingian and Darriwilian, the Pingliang Formation to Sandbian and the Beiguoshan Formation to Ordovician Katian.

Cyclostratigraphy study has conduct on the lower Pingliang Formation (about 34 meters thick) on the Pingliang section(Fang et al., 2016).By lithology features and magnetic susceptibility data, Fang et al. (2016)found obvious Milankovitch cycles in the stratigraphic thickness of 15cm to 27cm, 23cm to 38 cm and 85.5cm to 124 cm, which were interpreted as corresponding to precession, obliquity and short eccentricity cycles, respectively. In addition, the author estimated duration of studied stratigraphic interval of about 3.22 Myr or 3.38 Myr.

Ourpreliminary work on the Ordovician in the southwestern Ordos was conducted on the Qishan section. We ascertained the stratigraphic synthesis and surveyed the lithology (Fig.1a, 1c, 1d). There are well developed sedimentary cycles, with thickness of 2 cm -5 cm or 2cm - 15 cm in the top of Pingliang Formation (Fig.1c1, 1d) and Lower Majiagou Formation (Fig.1c4). The content of $CaCO_3$(wt%) varies in periodicity (Fig.1e). This periodic variation of $CaCO_3$(wt%) also happens in the massive mudstone (Fig.1c2, Fig.1e) in the Pingliang Formation and massive carbonate rocks in the Majiagou Formation.Thermal demagnetization for the representative samples (mudstone and limestone) shows that there are two NRM components, one is the low-temperature component which carried by goethite and would be the secondary NRM. Other is middle-high temperature component, which carried by magnetite and would be the ChRM. The paleomagnetic data from about 60 stratigraphic levels build up a preliminary geomagnetic polarity column. These data show a good prospect to build a high-resolution Ordoviciangeologic timescale in SW Ordos.

Key words: multiple stratigraphy, Ordovician, Ordos, IGCP652

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