### **ORIGINAL PAPER**



# Micro-Scale Iron Smelting in Early Iron Age to Mongol Period Steppe Communities of North-Central Mongolia and its Implications

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#### **Abstract**

Given the high level of technological sophistication involved in iron smelting, a common assumption held is that small mobile communities of the Mongolian steppe relied on trade with larger, settled, manufacturing centers for the acquisition of iron objects. Recent archaeological investigations in Mongolia suggest, however, that mobile pastoralist households and communities maintained a very active iron production industry. Although mounting evidence clearly points to the presence of household and community-based production, less is known about the level of technology employed by cottage industry scale manufacturers. In this paper we present the findings from excavations of mobile pastoralist dwellings and furnaces from sites in the Tarvagatai Valley of north-central Mongolia dating between 400 BC –AD 1300 that include a small assemblage of iron and iron-related objects bearing evidence of bloomery production. This material not only helps further substantiate that mobile communities in Mongolia had their own means of metal production but also indicates the innovative implementation of an existing technique at a scale previously deemed too small to be practical except in marginal steppe environments.

 $\textbf{Keywords} \ \ \text{Mongolia} \cdot \text{Steppe communities} \cdot \text{Iron production} \cdot \text{Scale} \cdot \text{Early Iron age} \cdot \text{Xiongnu} \cdot \text{Mongol empire} \cdot \text{Household production}$ 

### 1 Introduction

A recent metallographic study of 51 iron bushings from the axles of horse-drawn wagons excavated from a royal Xiongnu tomb in the Golmod 2 site, dated to the second century BC to first century AD, and located in Arkhangai Province, noted that all but one bushing was manufactured using bloomery technology and then forged into shape (Park et al. 2018). These royal wagons were often lavishly decorated with Chinese style ornaments and for a time were seen as physical

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evidence that both the economic and sociopolitical development of mobile pastoral societies was dependent on neighboring sedentary states (e.g., Bentlry, 1998; McNeill 1963). Subsequent research has sufficiently dispelled the notion that the nomadic sociopolitical tradition was reliant on external support (e.g., Honeychurch 2015).

Meanwhile, a burgeoning body of archaeometallurgical studies has documented the presence of a distinct metallurgical tradition among Mongolian mobile pastoralists (Park et al. 2008, 2010, 2018). For example, it has recently been determined that the bloomery iron-based technological tradition was established during the Xiongnu state period (ca. 200 BC to 100/150 AD) and consistently served as the primary method of iron production as late as the Mongol Period (12th to fourteenth century AD). This is in contrast to the Chinese style of iron technology, which was predominantly based on cast iron (Wagner 1996). While evidence of bloomery iron produced in China has been documented (Mei et al. 2015; Wagner 1999, 2008: 246), it is now widely accepted that knowledge of bloomery technology was transmitted from western Asia across the steppes to northwest China perhaps as early as 900 BC (Mei et al. 2015). It is important to note, however, that once the production of cast iron became well



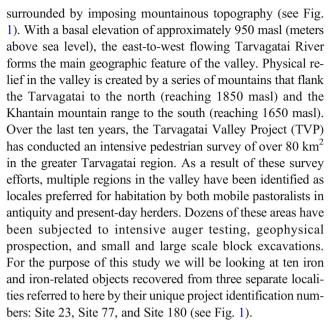
established in central China, around the sixth century BC, bloomery iron became exceedingly scarce in China (Wagner 2008: 246). Recently, bloomery furnaces have been discovered in China (Larreina-Garcia et al. 2018), but these are late, dating to the Qing Dynasty (AD 1636–1912). In addition, studies on Xiongnu bronze technology highlight a preference by steppe metallurgists to use arsenic (As) as a major alloying element as opposed to Chinese bronze production, where there was a profuse use of lead (Pb) and tin (Sn) for alloying (Park et al. 2011, 2017). Overall, a growing body of evidence clearly points to a unique metallurgical tradition in Mongolia that was not solely dependent on Chinese production centers or technological traditions.

The firm establishment of Mongolia's distinct metallurgical tradition has inspired scholars to further question the extent to which production took place. Early investigations have established that large population centers such as Karakorum were also centers of metal production (Park and Reichert 2015). Mongolian and Japanese scholars have discovered large sites that appear to be production centers where the sole focus is the manufacturing of metal and ceramic goods (Chunag 2018). Recent work on iron objects recovered from medieval campsites in eastern Mongolia has also observed micro-scale steelmaking through the recycling of small cast iron scraps (Park et al. 2019a, 2019c). This creative "cast iron-dependent" iron tradition, that allowed local steppe communities to successfully manufacture needed goods despite a lack of available natural resources, points to a level of technological flexibility unique to the mobile pastoralist lifeway (Park et al., 2020).

Although scientific research on Mongolian bronze and iron production is growing at a significant rate, it is still very preliminary and far from being sufficient for comparative discussions about production methods across different regions of the steppe (Park et al. 2019a: 556). Understanding regional variability in production patterns marks an important next step for Mongolian archaeology, as it will allow us to gauge the level of input from non-local metallurgical traditions such as Central Asia, Siberia, and China. To help contribute to the discussion of regional variability, this paper presents a small assemblage of iron and iron-related objects recovered from the excavations of habitation sites in the Tarvagatai Valley of north-central Mongolia (Fig. 1). These sites range in age from the Late Early Iron Age (ca. 419 BC) to the Mongol Period and thereby provide an important diachronic perspective on metallurgical traditions.

# 2 Comments on Project Area, Artifacts, and Sites

The Tarvagatai Valley is located within the forest-steppe region of the Baikal Rift Zone in north-central Mongolia and consists of approximately 120 km<sup>2</sup> of inhabitable land



The general appearance of each artifact is shown approximately to scale in Fig. 2 (except object #10 with its own scale given at the lower right corner) and each artifact is labeled with a number for identification. Object #1, with its respective top and bottom views provided at the upper left and right-hand side of Fig. 2, is a small lump of iron displaying an irregular surface profile covered with a layer of corrosion. This object was recovered from test excavations conducted at Site 77, which is located in a confined mountain valley on a small T3 terrace of a tributary to the Tarvagatai River. Test excavations were conducted at the site during the 2018 field season for the purpose of ground-truthing a geophysical survey conducted in the small river valley. Object #1 was found in situ in Test Unit #3 approximately 10 cm below the ground surface in association with refuse material that included fragmented and butchered bone, ceramic fragments, and small lithic materials.

During the 2013 field season, excavations discovered a mobile dwelling space at Site 77 that dated to  $2360 \pm 25$  BP (UGAMS# 13204: cal. 511–387 B.C., 95% probability; Fig. 3). This mobile dwelling space is located approximately 7 m north of the test unit where Object #1 was discovered. Spatial analysis of cultural materials associated with the mobile dwelling show that access to the interior dwelling space was from the south and that refuse material was removed from the dwelling through this access point and scattered to the south (Gardner and Burentogtokh 2018). Ethnoarchaeological studies of cultural material distribution around ephemeral dwelling spaces show that 7 m is well within the average range of refuse distribution (Binford 1990; Gamble 1991; Kroll and Price 1991). Lastly, soil survey and micromorphological analysis of the terrace's soil structure show that no high energy erosional events had taken place on the terrace within the last 2500 years (Ostericher 2016). Given the totality of the evidence we are confident in stating that the iron



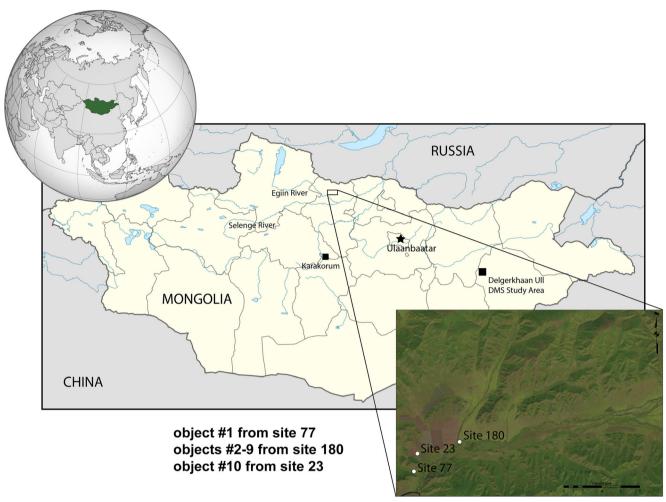


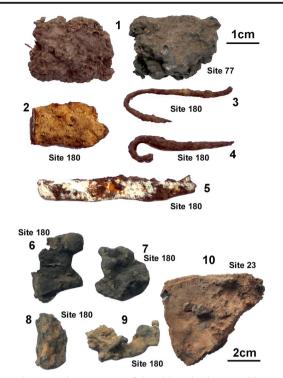
Fig. 1 Map of Mongolia showing the location of the archaeological sites in the Tarvagatai, Delgerkhaan Uul, and Karakorm areas mentioned in the text, with an inset (upper left) positioning Mongolia in the globe and another (lower right) locating the sites under consideration in the Tarvagatai Valley

object was inadvertently included in the material group that was most likely refuse thrown out of the identified mobile dwelling.

Objects #2 and #5 represent iron artifacts in the form of a rod or a plate, objects #3 and #4 possess the characteristics of a fish hook, and objects #6-9 are pieces of slag revealing surface features characteristic of a solidification reaction. These objects were recovered from the block excavation of a house pit located at Site 180 that dates to approximately AD 1309– 1412 (date based on 8 calibrated radiocarbon dates at the 2sigma range; see Gardner et al. forthcoming, see also Fig.3). Excavation of the site first encountered a 2–4 cm thick mottled charcoal lens that contained butchered faunal remains at approximately 13 cm below ground surface. Within the mottled charcoal lens a complete, premature Capra aegagrus hircus was found in a compact spherical shape. The fact that the C. aegagrus hircus was complete, in a tightly packed spherical shape, and lacked evidence of postmortem animal scavenging, suggest that the animal had been intentionally placed in a perishable container for ceremonial purposes. Fill inside of the housepit feature was approximately 30-33 cm thick and consisted of a homogeneous gray (7.5 YR 5/1) loess fill with mottled charcoal and ash flecking throughout. The floor of the housepit was lined with a 4–5 cm thick birch bark matting and below the birch bark flooring, in the northwest corner of the structure, a complete, premature, *Ovis aries* was discovered in a small  $12 \times 22$  cm rectangular pit.

Based on current evidence, the dwelling space is identified as a semi-permanent structure that either acted as a year-round habitation or a well-maintained seasonal dwelling space that was continually reused for an extended period of time. The homogenous nature of the fill and the close correlation of eight separate radiocarbon dates from faunal material found in various levels throughout the fill suggest that the dwelling was occupied for a set period of time and then intentionally filled with sediment that contained refuse material (including the objects analyzed here) that had accumulated during the occupation of the housepit. This interpretation is further supported by the presence of the premature *O. aries* and *C. aegagrus hircus* at the uppermost and lowermost levels of the structure, as





**Fig. 2** The general appearance of the objects in the assemblage under consideration. Object #1 is an iron bloom with an irregular surface profile; #2-#5 practical iron items forged out of bloomery iron; #6-#9 pieces of slag with surface features characteristic of a solidification reaction; #10 a fragment of baked clay with some slag particles attached to its burnt surface. The objects are shown approximately to scale except #10 with its own scale given at the lower right comer

these two animal internments appear to mark a ritual "opening" and "closing" of the dwelling space.

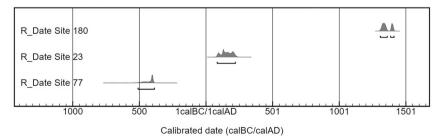
Object #10 is a fragment of burnt clay with some slag particles attached to its surface that was recovered from test excavations at Site 23. Site 23 is located on the edge of a small marsh that developed in an abandoned oxbow lake along the Tarvagatai River. The site was originally identified as a large collection of cultural material exposed in a modern farm field. Geophysical prospection discovered a large anomaly, and test excavation of the anomaly identified the remains of a bloomery furnace. Bulk sediment samples collected as part

of the excavation of the furnace recovered a charred *Pinus* species cone scale fragment which returned an AMS date of  $1860 \pm 20$  BP (UGAMS# 43624: cal. AD 85–222 95.4% probability; see Fig. 3), placing it within the late Xiongnu tradition.

## 3 Metallographic Examination and Results

One or more specimens were taken from each of the objects presented in Fig. 2 for metallographic examination (Scott and Schwab 2019). The specimens were mounted and polished following standard metallographic procedures and then etched using a solution of 2% nitric acid by volume in methanol, for investigation using an optical microscope and a JEOL JSM-5410 scanning electron microscope (SEM). The microstructures observed were used to assess the carbon concentration, which was specified according to weight fraction. The presence of other minor elements such as silicon (Si), calcium (Ca), and aluminum (Al) was assessed using the energy-dispersive X-ray spectrometer (EDS) included with the SEM, the nominal detection limit of which is within a few tenths of 1%.

Figure 4a and b present optical micrographs illustrating the structure of two cross sections of object #1 in Fig. 2. In both micrographs, metallic parts appear brighter than dark areas of varying sizes corresponding to spaces filled with either nonmetallic materials or corrosion products of metals. Figure 4c and d, optical micrographs, provide a magnified view of the location marked by arrow A in Fig. 4a and b, respectively. Figure 4c consists primarily of bright ferrite grains of almost pure iron where some dark regions of nonmetallic materials are scattered. In contrast, the pearlite structure of the Fe-C alloy system forms the dark background of Fig. 4d with a little ferrite precipitated mostly in the bright boundaries between pearlite areas. Figure 4e, a SEM micrograph enlarging the spot at arrow B of Fig. 4b, visualizes the two constituents of pearlite, ferrite and cementite, arranged in alternating layers. Given the carbon content of ferrite and pearlite being 0.02% and

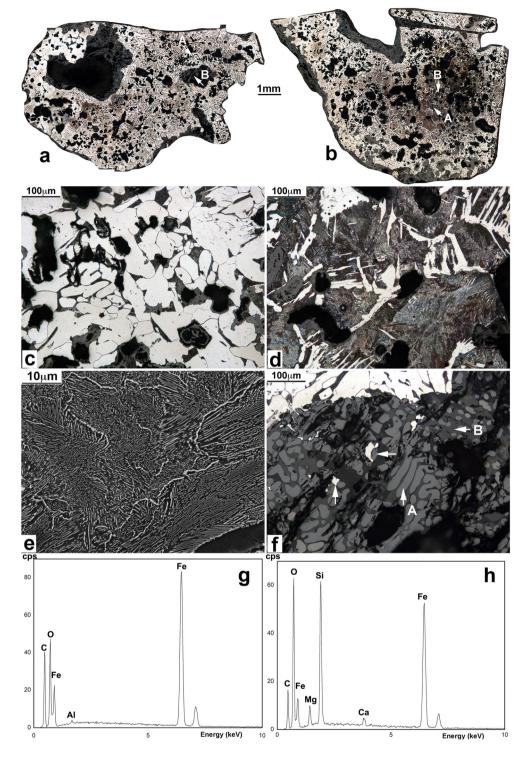


**Fig. 3** Graphical illustration of the results from radiocarbon measurements for each site presented in this paper. Analysis was conducted by the Center for Applied Isotope Studies at the University of Georgia. Dates presented in this graphic and in the text were calibrated with the Oxcal online software platform using the Intcal13.14c calibration

data set (Ramsey 2009). Exact sample information from top to bottom: Site 180 UGAMS# 36634, 580 B.P.  $\pm$  20 (cal. AD 1309–1412 2 $\sigma$ ), Site 23 UGAMS# 43624, 1860 B.P.  $\pm$ 20 (cal. AD 85–222 1 $\sigma$ ), and Site 77 UGAMS# 13204, 2360 B.P.  $\pm$ 25 (cal. 511–387 B.C. 1 $\sigma$ )



Fig. 4 Optical and SEM micrographs and EDS spectra taken from the specimens of object #1 in Fig. 2. a); b) Optical micrographs covering the entire cross sections at two different locations; c); d) optical micrographs enlarging the vicinity of arrow A in Fig. 4a and b, respectively; e) SEM micrograph providing a highly magnified view of the spot at arrow B in Fig. 4b; f) optical micrograph magnifying the vicinity of arrow B in Fig. 4a; f); g) EDS spectra taken at arrows A and B in Fig. 4f, respectively



0.77%, respectively, the overall carbon concentration as inferred from the structure of Fig. 4c is negligible while that of Fig. 4d is approximately 0.6%. Evidently, the specimen from which Fig. 4a was taken contains little carbon while a notable carbon level is confirmed in Fig. 4b. It is important to note that the dark high carbon area is concentrated in the vicinity of

arrows A and B, suggesting that the general carbon level of object #1 is not significant.

Figure 4f, an optical micrograph, provides an enlarged view of the location at arrow B in Fig. 4a, which is one of the numerous dark nonmetallic areas distributed in both Fig. 4a and b. Aside from the bright ferrite grains positioned near



the upper edge, Fig. 4f consists of two different phases as represented by those marked by arrows A and B. Figure 4g and h, EDS spectra taken respectively from the spots at arrows A and B, show that the phase at A consists primarily of iron oxide while the major component of the phase at B is oxides of iron and silicon (Si) contaminated with a little magnesium (Mg) and calcium (Ca). (The peak in carbon [C], which is due to a thin carbon layer having been coated on to the specimen surface for the SEM examination, should be ignored.) The peculiar shape of the phase at A indicates that it was precipitated from a solidification reaction with the phase at B solidified subsequently to form the dark background. The unique shape and chemical composition indicate that the phase at A is wustite while that at B corresponds to favalite, two major components of slag generated as a byproduct in the smelting of bloomery iron. The tiny bright areas some of which are marked by unlabeled arrows in Fig. 4f represent islands of iron included in the mass of slag.

Figure 5a and b present optical micrographs showing the structure of the specimens taken from objects #4 and 5, respectively. Ferrite grains form the bright background in both micrographs. A little pearlite is preferentially located in the dark areas along the ferrite grain boundaries of Fig. 5a. No pearlite is observed in Fig. 5b where large ferrite grains form the background containing a number of dark nonmetallic inclusions elongated along the forging plane. EDS analysis showed that they also consisted of wustite and fayalite, as

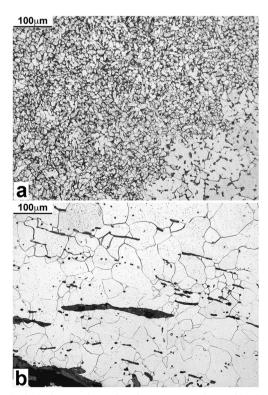


Fig. 5 Optical micrographs. a); b) Microstructures observed in objects #4 and #5 in Fig. 2, respectively

discussed above in reference to Fig. 4f. The specimens taken from objects #2 and #3 were found to have microstructures not much different from those presented in Fig. 5a and b. Despite the minor differences in the fraction of pearlite, the density and distribution of nonmetallic inclusions and the differing grain sizes, objects #2 through #5 can be considered similar in that they could be forged out of an iron material displaying characteristics as observed in object #1.

Figure 6a, b, and c, optical micrographs showing respectively the structure of objects #6, #7, and #9, were all made of similar materials. The areas marked by arrows A, B, and C in Fig. 6a are filled with the wustite, fayalite, and non-crystalline glassy phases, respectively, which serve as the three main constituents of slag from the bloomery process for iron smelting. EDS analysis shows that the wustite and fayalite phases in Fig. 6a were almost identical in chemical

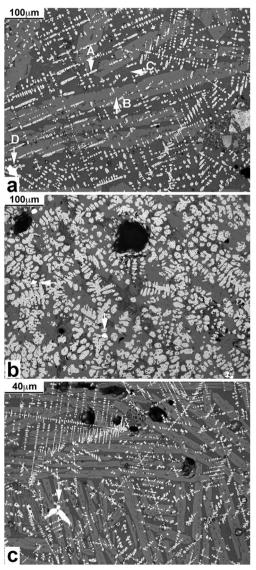


Fig. 6 Optical micrographs. a)-c) Microstructures observed in objects #6, #7, and #9 in Fig. 2, respectively



composition to those positioned at arrows A and B of Fig. 4f, respectively. Arrow D in Fig. 6a indicates a particle of almost pure iron, which also has its counterpart in Fig. 4f at the unlabeled arrows. The structure shown in Fig. 6b and c is also seen to consist of the same constituents. Notable differences, however, are observed in their exact shape and fraction in each micrograph, reflecting variations in thermochemical conditions given while the slag objects were generated through a solidification reaction. Particles of almost pure iron are also included as seen in Fig. 6b and c at the arrows.

### 4 Discussion

The microstructural data above reveal that object #1 in Fig. 2 is an iron bloom containing numerous slag inclusions. Its general carbon content is negligible except in some restricted areas. Microstructures comparable to this were also observed in objects #2-#5, practical items, with differences noted only in the density and shape of slag particles. These were all forged out of almost pure iron with a reduced density of slag inclusions in the form of elongated ribbons reflecting the degree and direction of plastic flow during fabrication. Figure 2 also presents small pieces of slag (#6-#9) generated as byproducts from iron smelting. In terms of the chemical composition of key constituents, these artifacts were nearly identical to the nonmetallic inclusions found in objects #1 and #2-#5, confirming that they originated from the bloomery process. The artifacts in Fig. 2 therefore point consistently to smelting of iron that was practiced on-site for the production of a raw material to be forged into practical articles. Further support for this premise is found in object #10, a fragment of baked clay with slag particles attached that was taken as a sample from the bloomery furnace feature discovered at Site 23 that dates to  $1797 \pm 20$  cal BP mentioned above.

To the modern mind accustomed to mass production and circulation of most industrial materials, a small iron artifact such as object #1 of approximately  $2.5 \times 2.0 \times 1.5$  cm in volume may seem nothing but discarded waste with little practical value. What is important to note is that the thermochemical process for iron smelting requires a strict control over reaction temperature and atmosphere but no restriction on its scale. This object is therefore large enough of a mass to provide more than enough material for making the practical metal items in the assemblage under investigation (Fig. 2, objects #2-#5). Although these objects come from three separate sites that date to different time periods, the likelihood that all are byproducts of a micro-scale mode of production is not a stretch as there is a growing body of evidence that indicates this was a common practice among mobile pastoralist groups in antiquity (Park et al., 2019a, b).

The metallographic analysis of a number of cast iron fragments, mostly weighing 20.0 g or less, from the Delgerkhaan Uul region of eastern Mongolia were noted as having been individually treated for steelmaking through decarburization in the molten state (see Fig. 1; Park et al. 2019a). Moreover, the materials analyzed from the Delgerkhaan Uul region come from multiple habitation sites suggesting that the technique was routinely practiced among medieval nomadic communities (Park et al. 2019b). The identification of a similar scale of production mode for the smelting of bloomery iron practiced at multiple sites for over a thousand years in the Tarvagatai Valley further supports the premise that mobile households and communities developed micro-scale production methods that provided them with economic flexibility to produce utilitarian items.

### **5 Conclusion**

As previously stated, metallographic investigation in Mongolian archaeology is still very preliminary and our understanding about regional variability is an area in need of attention. To help contribute, this paper presents the metallographic investigation performed on an artifact assemblage consisting of a small iron bloom, four finished iron articles, four pieces of slag, and a fragment of baked clay recovered from habitation sites in the Tarvagatai Valley of north-central Mongolia. The objects examined were all related technologically, pointing to an extremely small-scale process implemented for the smelting of bloomery iron, which would subsequently be forged into practical items. In terms of its scale, this method parallels the one practiced for steelmaking in medieval communities at Delgerkhaan Uul in East Mongolia.

With the unique iron and steel making processes in their possession, local steppe communities had a capacity to sustain themselves without external support for these key strategic materials. A similar observation was also made in the investigation of metal objects from royal Xiongnu tombs (Park et al. 2010, 2018) and the former capital of the Mongol empire, Karakorum (Park and Reichert 2015). Findings associated with our research here parallel that of previous work which suggests Mongolian mobile pastoralists developed a flexible iron tradition that was maintained at multiple scales from political centers down to remote steppe communities. Moreover, both previous investigations and this study indicate that the bloomery-based technology was developed at very early stages of iron making in Mongolia and maintained through to the medieval period. This fact indicates that Mongolian iron production in general was far removed from the Chinese style tradition based on the mass production of cast iron.

It is intriguing to see that nomadic people in Mongolia could secure independent and flexible iron acquisition by focusing particularly on the scale of existing methods, whether domestic or imported. The idea of implementing micro-scale processes was likely nucleated by equally micro-scale needs



common to most steppe communities. The success in this effort must have been a significant technological innovation, which could happen only in steppe contexts where nomadic inhabitants developed a flexible lifeway able to adapt to everchanging environmental, sociopolitical, and economic conditions.

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