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The Magnetic Susceptibility of the Late Quaternary Loess in North-East of Iran and Its Correlation with Other Palaeoclimatical Parameters

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***Abstract*—**Magnetic susceptibility (χ) is operational to identify of late quaternary glacial-interglacial cycles in loess-paleosol sequences. It is well accepted that many loess-paleosol sequences bear witness to cold-dry/warm-humid periods, well known as glacial-interglacial cycles, respectively. For this study, loess-paleosol sequence of north-east of Iran was magnetically investigated. The study area is situated at about 8 km away of Neka city, on the main road of Sari-Behshahr, in Mazandaran Province, north of Iran. The youngest deposits of study area are the late Quaternary wind-blown accumulations. In this study, the total number of 117 samples was collected from loess-paleosols units. After that, the natural remnant magnetization (NRM) and magnetic susceptibility (MS) of the samples were measured. Variation of MS of more than 110 loess samples was plotted to reveal the correlation of the MS and paleoclimatic changes. This study aims reconstruction of climatic changes (glacial-interglacial and stadials-interstadials cycles). To confirm our results we compared MS (χ) and the curves of other investigations in paleoclimatology. This correspondence abled us to recognize worldly events in the study area such as: Younger Dryas, the Last Glacial Maximum (LGM), deglaciation of Northern Hemisphere etc. The obtained magnetic data indicate that during almost 50 ka, at least two glacial-interglacial periods occurred in north-east of Iran. Further, variation of χ values revealed short period of climatically cycles known as stadials-interstadials. We recognized 4 stadials and a single stadial as colder sub-periods for S_0 (recently soil-paleosol) and S_2 (lower paleosol), respectively, Moreover, we recognized 6 warmer sub-periods (interstadials) for L_1 (upper loess) and one interstadial L_2 (lower loess).

***Keywords*—**Glacial-interglacial cycles, Iran, last glacial maximum, loess, magnetic susceptibility (χ), Neka, Stadials-Interstadials sub-periods, younger dryas.

I. Introduction

LOESS is deposits of windblown fine-grained angular particles that are accumulated during glacial periods in the glacial margins. Many loess sections contain fossil soils (paleosols) that bear witness to warmer and wetter climatic conditions corresponding to interglacial periods in contrast to the cold, arid environments of glacial intervals [1]. It is well accepted that variations of MS are comparable with the variation in the temperature; and we expected that possibly we would able to recognize an effect of the LGM occurrence in our study results.

Totally, large and rapid climatic changes occurred during the last glacial period (around 20,000 to 100,000 years ago) and during the transition period towards the present interglacial (the last 10,000 years, known as the Holocene). Also, the LGM was occurred around 22,000-18,000 years ago [2].

The LGM is conventionally defined from sea-level records as the most recent interval in Earth history when global ice sheets reached their maximum integrated volume [3], [4]. Growth of the ice sheets to their maximum positions occurred between 33.0 and 26.5 ka in response to climate forcing from decreases in northern summer insolation. On the other hand, ice sheets of all sizes, as well as Northern Hemisphere mountain glaciers, began to retreat at approximately at 19 to 20 ka [4].

Reconstructing the paleoclimate changes of Neka Loess in north-eastern Iran is important for providing our understanding of the pattern of paleoclimate changes of the region. The basic assumption of this study is that Loess units are transported and accumulated by the wind during the late Quaternary glacial periods of Northern Hemisphere (in this study only 50 ka was investigated); and paleosol units weathered during interglacial intervals. Furthermore, this study aims to confirm the capacity of MS of Neka loess to reconstruction of climatically changes by comparing the curve of χ values with the curves of other investigations in paleoclimatology.

The study area is considered as the southern margin of Mazandaran in terms of the main sedimentary structural zones of Iran. It is bounded by the Caspian Sea to the north. The study area was described and suggested as the loess-paleosol sequences of the Caspian Low land in Northern Iran, which provide detailed archives of climate and environmental change showing a close relationship to global cooling and warming trends for the Quaternary period [5].

Loess profile is found on the northern foothills of the Alborz Mountains near the city of Neka. It is approximately 10 m; although loess/paleosol sequences of area usually reached a maximum thickness of approximately 20 m. This zone consists of areas that are located in the north of the Alborz fault, and the northern coastal plain of Iran; and also, covered with thick layers of loess, to the east (Fig. 1). The study section which is informally named as Kolet Section (Fig. 2) falls between 36° 39' 44" N and 53° 23' 56" E. It is situated at about 8 km away of Neka city, almost opposite of Kolet Village (Fig. 3), near the main road of Sari-Behshahr, in Mazandaran Province, north of Iran. Optically Stimulated

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Luminescence (OSL) dates for studied section are measured [6] using absolute dating of the luminescence age estimates (Fig. 4).

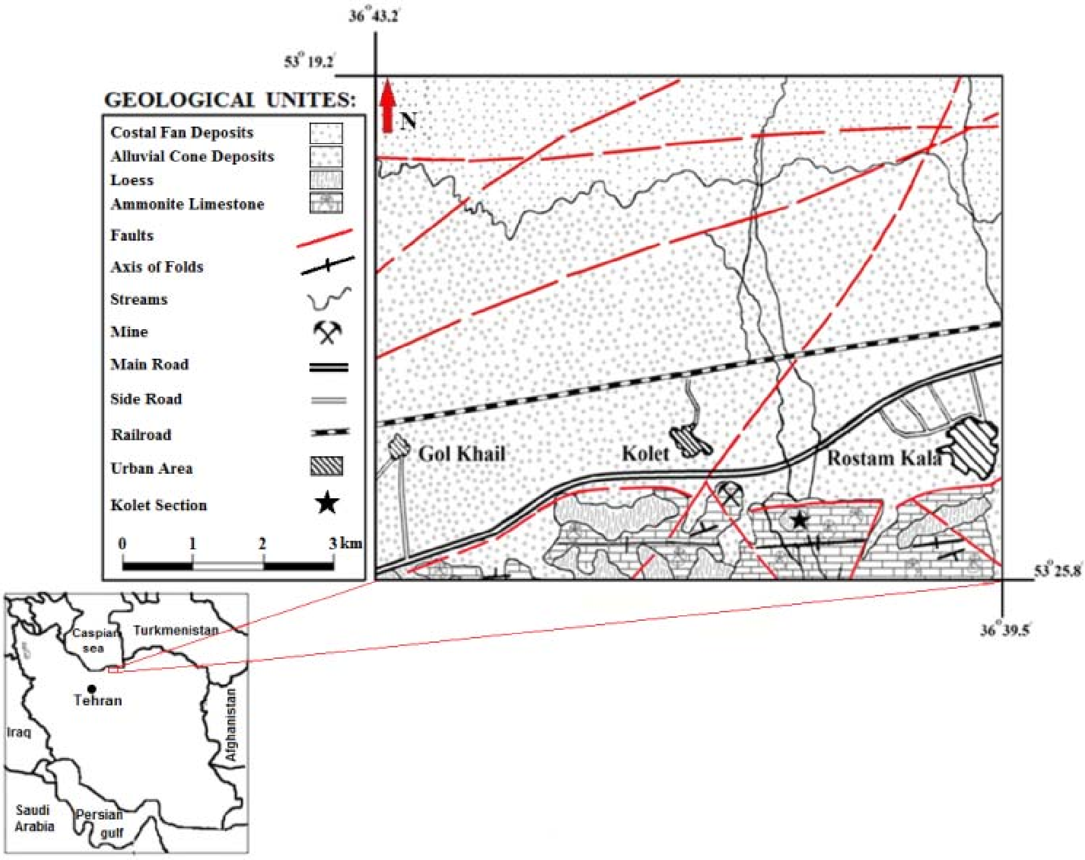


Fig. 1 The Geological Map of the study area, near Neka city, north-east of Iran. Note: Loess cover Jurassic limestone of the Alborz front hills

Fig. 2 The loess/palaeosol sequence of Kolet section, at Neka, Mazandaran Province, northern of Iran. The study section maximum thickness is approximately more than 10 m

II. Sampling and Methods

At first, 117 samples were packed from Kolet section into plastic packets. After then, NRM and variation of MS (χ) were measured, using Spinner (JR-6A) and using Multi-Function Kappabridge (MFK1-A), respectively (Fig. 5). For measuring NRM, we measured each sample at three axial directions xz, yz and xy, which are shown in Fig. 6. It is necessary to complete measuring of NRM for total samples, and after that we start to measure MS of samples. Accordingly, variation of MS of more than 110 loess samples was measured; and then was plotted versus stratigraphic column.

III. Results

1) According to Fig. 4, NRM and MS show matchable changes. In other words, wherever NRM variation increases, variation of MS increases; and wherever variation of NRM decreases, variation of MS decreases, too. Also, NRM, like MS, shows four peaks for the three well developed soil and paleosol horizons, (S_0), (S_1) and (S_2); two prominent peaks for the (S_0) and two peaks for two paleosol horizons, (S_1) and (S_2). Moreover, NRM values show one small peak at about the bottom of (L_1), exactly corresponding to the age of 37.8 ± 3.6 ka.
2) The MS values show four fluctuations for the well-developed soil (S_0) and one fluctuation for Lower Paleosol horizon (S_2); and in contrast, 6 swing curves for

Upper Loess (L_1), and one curve for L_2, Lower Loess horizon (Fig. 6 (a)).

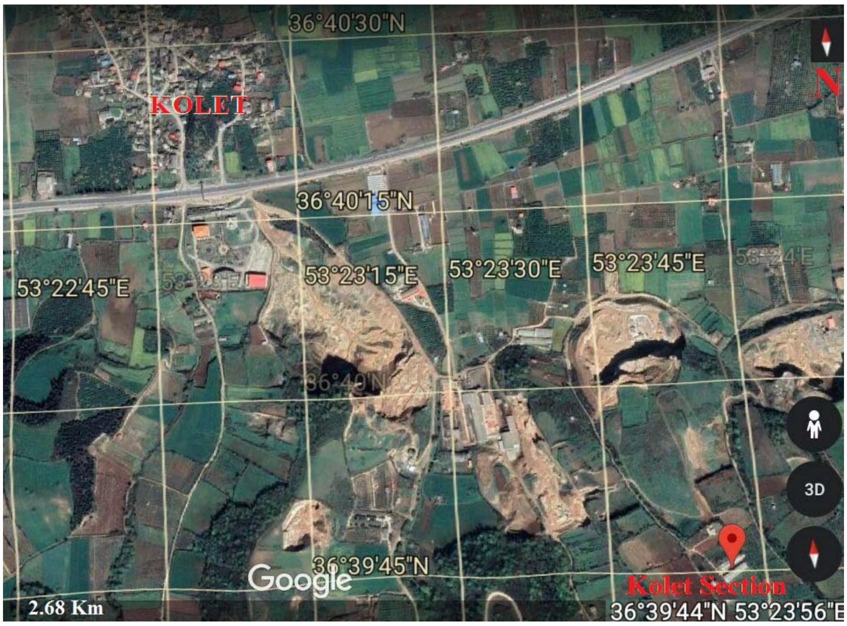


Fig. 3 Satellite view of study area. Buffed yellow hills are known as Neka loesses; Study section is marked with an open red star; Kolet village is located on northwest of section opposite the main road of Sari-Behshahr

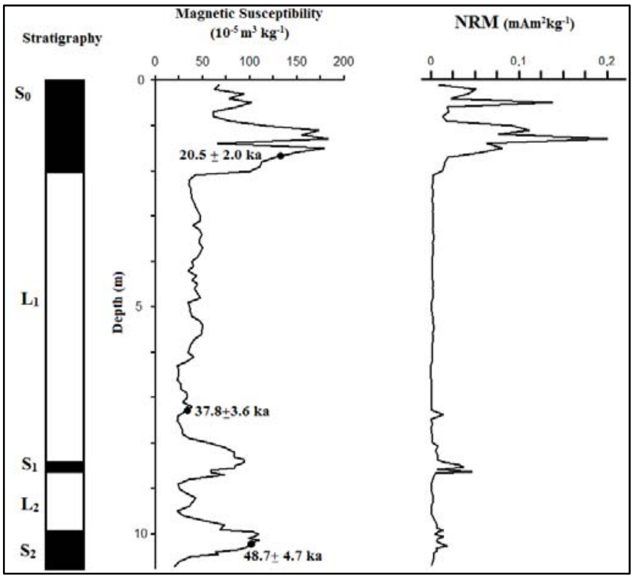


Fig. 4 Variation of MS (χ) and NRM for loess-paleosol sequence of Kolet section, at Neka, northeast of Iran. Note: Solid circles are OSL dates

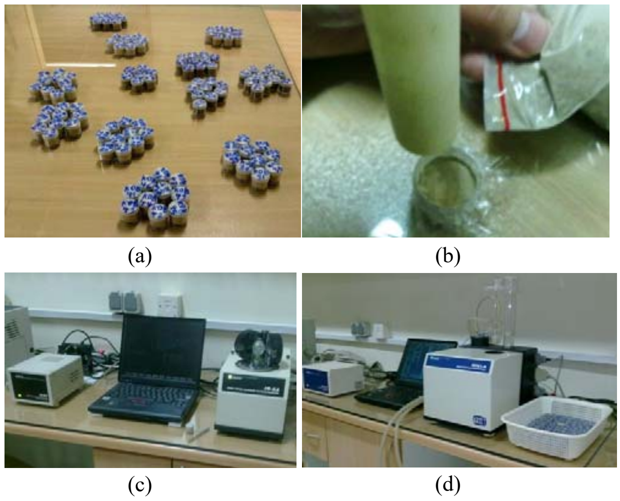


Fig. 5 The steps of laboratory techniques and methods. (a) 117 samples of Kolet section, at Neka, northeast of Iran; (b) a sample of loess deposit during packing and preparing for measurements and experiments; (c) using Spinner (JR-6A) to measurements of NRM; (d) using Multi-Function Kappabridge (MFK1-A) to measurements of MS (χ)

IV. Discussions

Variations of MS (Fig. 7 (a)) enabled us to investigate about dry-cold and moist-warm periods during late Quaternary. The χ values show prominent peaks for Recent Soil (S_0), Upper Paleosol (S_1) and Lower Paleosol (S_2); which probably refer to warmer and wetter conditions of interglacial periods. Notice that, S_0 started to form almost 20.5 ± 2.0 ka years ago; and S_1 formed more than 37.8 ± 3.6 ka years ago. Also, S_2 weathered almost around 48.7 ± 4.7 ka years ago. To confirm our data and results, we compared variation of MS with the curves of other investigations in paleoclimatology such as:

1) The curve of the result of an investigation which is named as "A 225 kyr record of dust supply, paleoproductivity and the oxygen minimum zone from the Murray Ridge (Northern Arabian Sea)" [7]. This curve is illustrated in Fig. 7 (c), at the right side.
2) A palynological study based on two 100-m long cores from Lake Urmia in northwestern Iran provides vegetation record spanning 200 ka [8]; which is illustrated in Fig. 7 (c), at the left side.
3) The curve of cores recovered from a thick sedimentary sequence in the Ioannina basin, on the western flank of the Pindus Mountain Range, northwest Greece [9] which is illustrated in the center Fig. 7 (c).
4) The curves of the North Greenland Ice Core Project members [10] and methane synchronization of the EDML which are from the European Project for Ice Coring in Antarctica (EPICA) Community Members [11]; are shown in Figs. 7 (b).
5) The curves of the oxygen isotopes of deep ice cores set from NGRIP [10] is based on the Greenland Ice Core Chronology 2005 (GICC05) timescale [12], [13]; EPICA [14] and Vostok Ice core [15] ; show in Figs. 7 (d), (e).

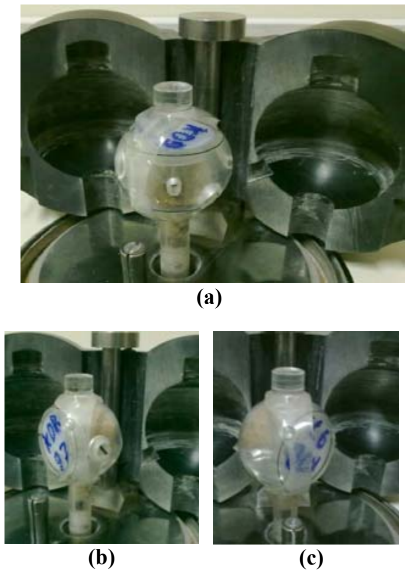
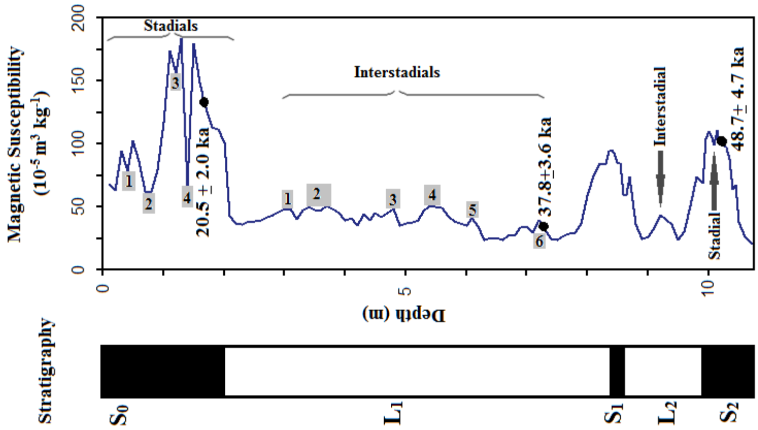
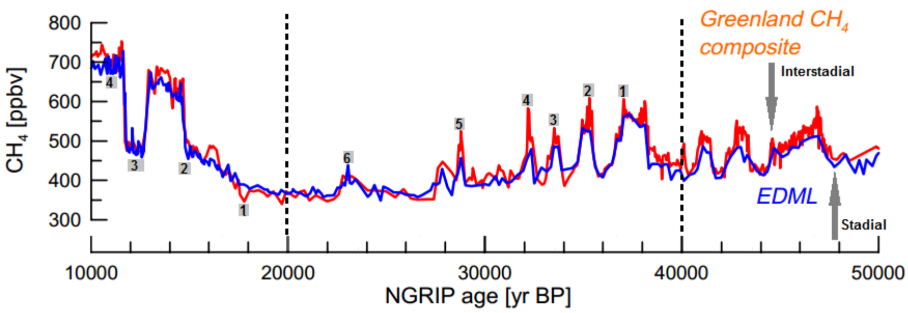


Fig. 6 Measuring of NRM; (a), (b) and (c) are measuring of NRM at xy, xz and yz axis directions, respectively

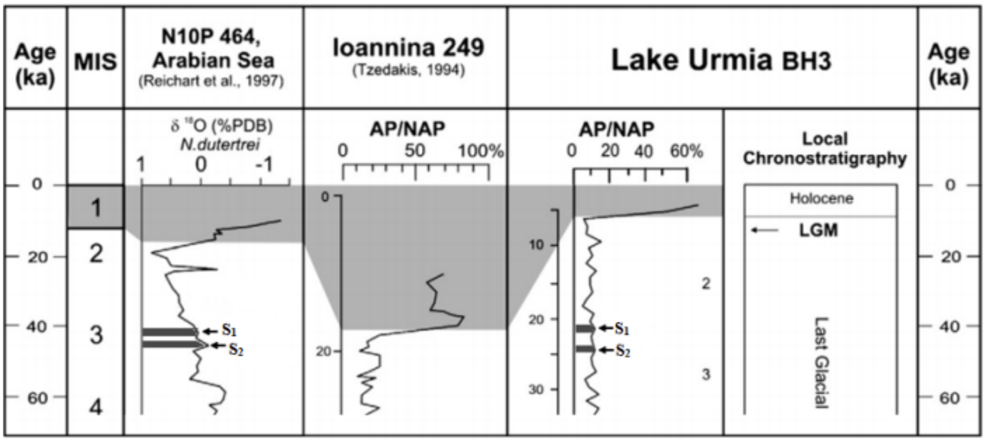


(a) Variation of MS for loess-paleosol sequences of Kolet section, NE of Iran

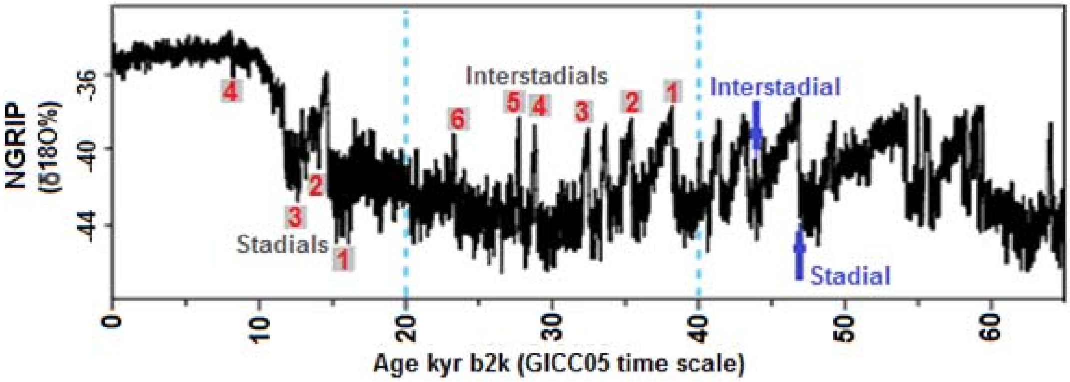


(b) Variation of stadials and Interstadials of Kolet Section versus CH4 records for Greenland [10] and EDML [11] [(1)]

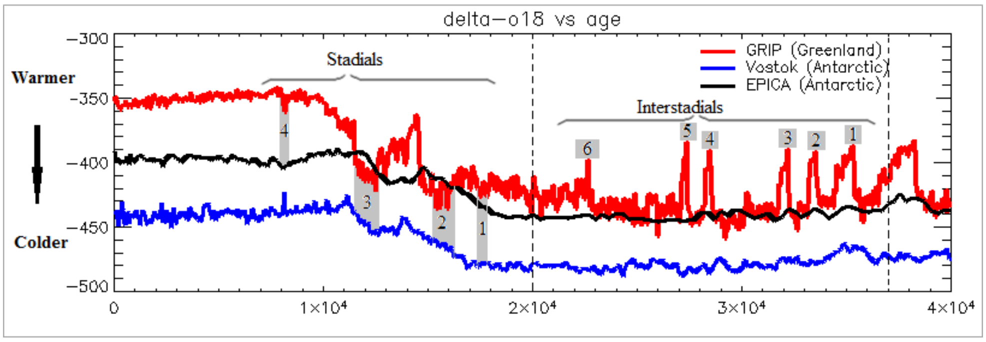
[1]For more see Supplementary Information of EPICA [11, p.12].



(c) Paleosol horizons (S_1 and S_2) VS variation of dust cores recovered of Northern Arabian Sea (right side); a curve of late Pleistocene long pollen record from Lake Urmia, NW of Iran (left side)



(d) The oxygen isotope data set from NGRIP [10]. GICC05 [17] ages are given in units of "b2k" with reference to the year AD 2000 [18]



(e) Stadials and interstadials of Kolet Section in compare with the curves of delta-O-18 from the GRIP, Vostok and EPICA ice cores [16]

Fig. 7 Variation of MS versus 5 other climatic investigations; Notes: Approximately 13,000 years ago, the Late Glacial Maximum (LGM) began; the end of the Younger Dryas occurred about 11,700 years ago; please note that comparison of variation of MS of loess-paleosol sequence of Kolet section (stadials and interstadials cycles) was pointed on the curves with numbers and arrows

V. Conclusion

1) The obtained magnetic data indicate that over the past 50 ka, there have been at least two glacial-interglacial periods in northeast of Iran; and since almost last 20 ka, there was no sign of occurrences of glaciations in the study area.
2) Based on variation of MS curve, it is acceptable and understandable that, L_1 plus original losses of S_0 were accumulated during the LGM; and after then probably S_0 formed during a deglaciation, which is comparable with deglaciation of Northern Hemisphere which started at 19 to 20 ka.
3) Variation of χ values versus stratigraphic column showed us an outlook to recognize short period of climatically

cycles known as stadials-interstadials. We recognized 4 stadials (colder sub-periods) for recently soil-paleosol (S_0); and also, a single stadial for both lower palaeosol (S_2) and upper palaeosol (S_1), separately. Moreover, we recognized 6 interstadials for upper loess (L_1) and one interstadial for lower loess (L_2).

4) Comparison of the diagram of palynological study of Lake Urmia in northwestern of Iran, and the diagram of analyses of sedimentary cores recovered from the Murray Ridge, northern Arabian Sea, and variation of MS of loess-paleosol sequence of Kolet section enabled us to recognize and correspond the probably position of S_1 and S_2 on diagrams of Lake Urmia and northern Arabian Sea, separately.
5) By comparing the curves of χ and NGRIP and GRIP, it is recognizable that the occurrence of stadials and interstadials probably were the worldly events. For example, stadial number 3 on the S_0 is occurred almost at the end of the Younger Dryas, at the about 11,700 years ago.

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