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Author(s):
Nourgaliev, Danis K.; Heller, Friedrich; Borisov, Anatoly S.; Hajdas, Irena; Bonani, Georges; Iassonov, Pavel G.; Oberhänsli, Hedi

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Very high resolution paleosecular variation record for the last ~1200 years from the Aral Sea

Danis K. Nourgaliev,[1] Friedrich Heller,[2] Anatoly S. Borisov,[1] Irena Hajdas,[3] Georges Bonani,[3] Pavel G. Iassonov,[1] and Hedi Oberhänsli[4]

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[1] A record of geomagnetic paleosecular variation (PSV) spanning the last ~1200 years has been obtained from two lacustrine sediment cores from the north part of Aral Sea (Kazakhstan). Magnetic susceptibility and NRM intensity have been used for correlating between cores and reconstructing composite core data. The main swings and fine details of declination and inclination records correlate well between both cores. A very high sedimentation rate (up to 25 mm per year) due to recent tectonic activity of the region provides a very high resolution PSV record for the interval from 450 ± 100 years BP to 655 ± 65 years BP. The results which have been dated by eight AMS radiocarbon age determinations, suggest that a 200–400 years secular variation period with amplitudes in declination and inclination up to 10–15° existed regularly during the time interval 0–1200 BP. Amplitudes of the PSV record from Aral Sea are not reduced and smoothed by postdetrital magnetization processes. They adjoin to the historical data model and are considered to represent a reliable paleosecular variation record for the Aral Sea region for the last ~1200 years. *INDEX TERMS:* 1519 Geomagnetism and Paleomagnetism: Magnetic mineralogy and petrology; 1522 Geomagnetism and Paleomagnetism: Paleomagnetic secular variation; 4239 Oceanography: General: Limnology. **Citation:** Nourgaliev, D. K., F. Heller, A. S. Borisov, I. Hajdas, G. Bonani, P. G. Iassonov, and H. Oberhänsli, Very high resolution paleosecular variation record for the last ~1200 years from the Aral Sea, *Geophys. Res. Lett.*, *30*(17), 1914, doi:10.1029/2003GL018145, 2003.

1. Introduction

[2] Recent and historical geomagnetic data of the last 400 years have been used successfully for reconstructing secular variations and magnetohydrodynamic motions in the outer core [*Jackson et al.*, 2000]. Archeomagnetic and limnomagnetic data allow for similar reconstructions even further back in time [*Constable et al.*, 2000]. Naturally, accuracy and validity of such models are inferior to historical, observatory and satellite models but help describing the temporal and spatial behavior of the geomagnetic field on a thousand years time scale. Future progress in paleomagnetic field modelling does not only need accumulating data from new sites but also updating and correcting limnomagnetic NRM ages, and understanding the amplitudes of declination and inclination records. Limnomagnetic data are available from all continents (for summaries see [*Creer et al.*, 1983; *Evans and Heller*, 2003]). Their recent parts should be compared to and corrected by observatory and historical and well constrained archeomagnetic data. The interconnected different data sets may provide the most reliable extended PSV information in time and space.

[3] This paper presents PSV data for the last ~1200 years preserved in the recent sediments of Lake Aral (45°58.6′N; 59°14.5′E) which partly have been deposited at very high sedimentation rates. Particularly the data for the time interval from 450 ± 100 years BP to 655 ± 65 years BP may be extremely useful for future models of ancient geomagnetic field behavior.

2. Site Description, Core Collection and Sampling

[4] The Aral Sea basin is part of the Aral-Sarykamysh depression. Lake Aral began to form in the Early Holocene as summarized by *Boomer et al.* [2000]. Several terraces of unknown age have recorded largely changing water levels since then [*Bortnik*, 1996]. Lake Aral was one of the biggest salt lakes of the world before 1960. Its hydrological budget and water-level are largely determined by the inflow of two Central Asian rivers - Amu Darya and Syr Darya. The climate of the territory is continental and extremely dry. Modern summer precipitation is very low and insignificant for the water budget. Continued irrigation activity in the basins of the Amu-Darya and Syr-Darya has lowered the water level by 13 m in 1988 so that the lake has been divided into two separate lakes, North (Small) Aral and South (Large) Aral.

[5] We have drilled Lake Aral in summer 2002 using a corer based on the design of *Mackereth* [1958] for the acquisition of lake sediment cores up to 6.5 m in length in water depths up to 100 m [*Nourgaliev et al.*, 1996]. Three cores, each 70 mm in diameter and variable in length were taken from Chernyshov bay (northern part of Large Aral) - core Ar-7 (45°58.651′N; 59°14.471′E), core Ar-8 (45°58.231′N; 59°15.338′E) and core Ar-9 (45°58.582′N; 59°14.610′E). Cores Ar-7 and Ar-9 have been subsampled for paleomagnetic analysis in the field immediately after coring. The cored material was filled into non-magnetic cubic plastic boxes. These were packed into plastic bags, placed in magnetically shielding μ-metal boxes and transported to Kazan. Core Ar-8 was partly oxidized upon arrival in the Zurich laboratory after a long transportation time of >3 months so that the original NRM directions

[1]Faculty of Geology, Kazan State University, Kazan, Russia.
[2]Institut für Geophysik, ETH Hönggerberg, Zürich, Switzerland.
[3]Institut für Teilchenphysik, ETH Hönggerberg, Zürich, Switzerland.
[4]GeoForschungsZentrum Potsdam, Potsdam, Germany.

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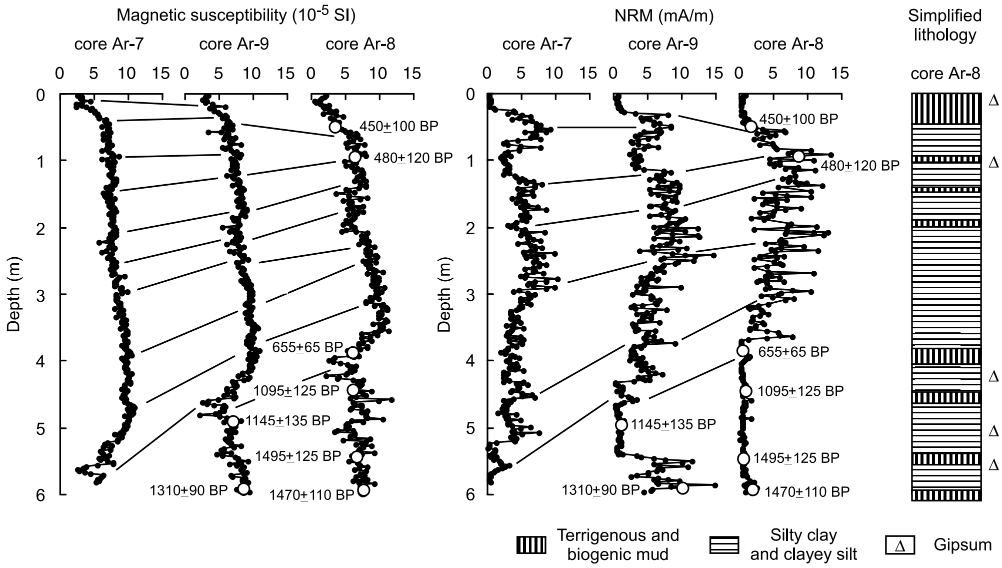

Figure 1. Down core logs of magnetic susceptibility, NRM intensity, ^{14}C ages and simplified lithology vs. depth for cores Ar-7, Ar-9, Ar-8. The sediments consist mostly of clayey silt and silty clay with very thin layers of gypsum which suggest a marked decrease in water depth. They are intercalated with terrigenous and biogenic mud. Correlation lines are based on wiggle matching of magnetic parameters constrained by AMS ^{14}C ages.

were not preserved, but some sedimentary organic rich levels could be used for ^{14}C dating.

3. Laboratory Investigations

[6] The natural remanent magnetization (NRM) of 847 Lake Aral sediment samples was measured using a three-axis ScT SQUID magnetometer at KSU, Kazan, Russia (cores Ar-7 and Ar-9) and the magnetic low field susceptibility (MS) was measured using a low-field susceptibility bridge (KLY-2). Pilot alternating field (AF) demagnetization was conducted using 16 samples from different parts of cores Ar-7 and Ar-9. The samples show remarkable directional stability. Median destructive fields are in the range of 20–40 mT. They do not contain significant viscous components because they were kept in non-magnetic space between sampling and laboratory measurement. Hence the remaining samples were not demagnetized. Instead, the initial NRM vectors have been used for the whole analysis.

[7] Similar though weakly expressed downcore variations of susceptibility are observed in all three cores (Figure 1). In combination with the more pronounced NRM variations which are again quite similar in all three cores, and the ^{14}C dates, a satisfactory inter-core correlation has been constructed. Generally, magnetic susceptibility and NRM intensity down-core are not correlated (Figure 1). Total organic carbon in core Ar-7 also does not correlate with low field susceptibility and paramagnetic magnetization, but correlates positively with NRM intensity, saturation magnetization and saturation remanence (Figures 1 and 2). Low field susceptibility is pre-dominated by paramagnetic minerals of terrigenous origin whereas the close positive correlation between organic content and remanence properties suggests a (probably) biogenic origin of the ferromagnetic minerals (evidence of greigite and magnetite from thermomagnetic curves).

[8] AMS radiocarbon data have been obtained from terrestrial macrofossils separated from sediment samples of cores Ar-8 and Ar-9 (Figure 1). Core Ar-7 did not contain layers from which organic carbon could be isolated successfully. Ages have been calibrated with the help of the OxCal program [*Bronk Ramsey*, 1995]. These radiocarbon data allow the development of a time-scale by assuming modern age at the top of the sediments and by linear interpolation between data points. They have been used together with pronounced features of down-core magnetic parameters (susceptibility and NRM) variations (Figure 1) for core correlation and construction of a composite core data set. Finally a stacked declination and inclination record was composed from cores Ar-7 and Ar-9 (Figure 3). Core

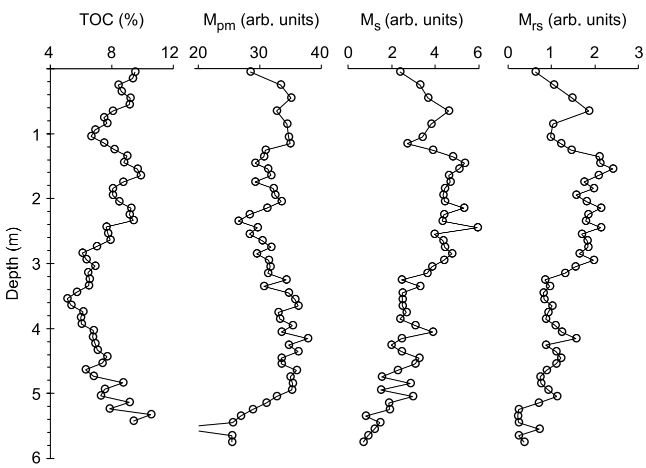

Figure 2. Total organic carbon TOC, paramagnetic M_{pm}, saturation M_s and remanent saturation magnetization M_{rs} in core Ar-7 as a function of depth. The magnetizations are given in the same arbitrary units. M_{pm} closely resembles MS (Figure 1), whereas the saturation magnetizations parallel the NRM intensity (see Figure 1) and to a large extent TOC.

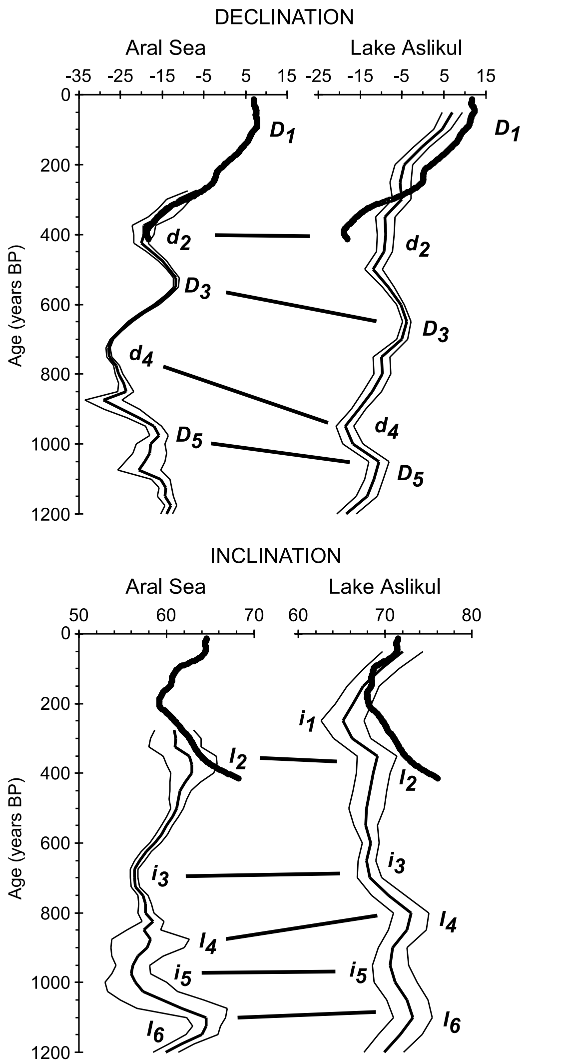

Figure 3. Comparison of the dated composite Aral Sea declination and inclination record with the PSV data from Lake Aslikul [*Nourgaliev et al.*, 1996, 2000] and modern data (thick black lines) for the last 400 years modelled for both localities [*Jackson et al.*, 2000]. Paleomagnetic data have been plotted as mean values of 40 year intervals with contours of 95% circles of confidence.

Ar-8 was excluded because alteration of the magnetic signal had proceeded too much at measurement time.

[9] The radiocarbon data show that the rate of sedimentation changes strongly through the sediment column (Figure 1). For instance, in the uppermost 1.3 meters of core Ar-9 the sedimentation rate is about 3 mm/yr, in the middle part (1.30–4.50 m) it is very high at about 16 mm/yr and in the bottom part the observed sedimentation rate amounts to about 1 mm/yr (interval 4.50–4.95 m) and about 6 mm/yr (interval 4.95–5.95 m). Low rates of sedimentation are connected with dry periods and low water level as we deduce from increasing gypsum concentration in the sediments (Figure 1). Very high sedimentation rates are possibly connected to very rapid subsidence which nowadays occurs in the deep-water western part of the Lake Aral basin.

4. Discussion

[10] The recent sediments of Lake Aral have recorded and faithfully preserved the local geomagnetic secular variations during the last 1300 years (Figure 3). Very smooth and consistent NRM declination and inclination variations in cores Ar-7 and Ar-9 represent a PSV record particularly well preserved and of very high resolution in the interval with the highest rate of sedimentation.

[11] The directional data of Lake Aral (45.98°N; 59.24°E) can be compared with the nearest record from Lake Aslikul (55.25°N, 54.7°E; [*Nourgaliev et al.*, 1996, 2000]) (Figure 3) disregarding the uppermost very soft sediment part of the Lake Aral PSV record (last 275 years BP) which has been distorted by coring and sampling procedures. The declination and inclination record back to 400 years BP, however, is very well supported in both lakes by modelled historical data [*Jackson et al.*, 2000]. The similarity offers the possibility to rotate the measured unoriented, relative values of declination of the whole Lake Aral composite core into absolute values. The declination record of Lake Aslikul is slightly smoothed in comparison with the historical data: amplitudes of declination and inclination variations are lower. In contrast, higher amplitude variations are observed in Lake Aral because of the 10–20 times increased rate of sedimentation for the interval between ~400–700 years BP.

[12] Declination variations recorded in Lake Aral and Lake Aslikul are very similar even in small details. All swings marked by *D*1, *d*2, *D*3, *d*4, *D*5 can be correlated and the swings *D*3, *d*4, *D*5 in Lake Aslikul appear to be older than in Lake Aral (Figure 3). The inclination records also correlate well with the historical model prediction. Probably due to slightly inaccurate age determination (or delayed NRM lock-in), the age of the minimum *i*1 in Lake Aslikul appears to be slightly older than the corresponding swing of the historical field model. The high rate of inclination change near ~400 years BP in the historical field inclination model - possibly being due to an edge effect at the end of the time series data used - is reflected by the inclination maximum (*I*2) near this age in both limnomagnetic records (Figure 3). This inclination maximum is observed all over Europe [*Turner and Thompson*, 1981; *Frank et al.*, 2002]. This maximum - recorded in the British Lakes as feature α - has an age of about 325–375 years BP in the Aral-Aslikul region, but is younger in most of the other European records. British and French archeomagnetic data provide an age of this inclination feature of ~275 ± 50 years BP [*Daly and Le Goff*, 1996]. The East European archeomagnetic data (Bulgaria, Hungary, Ukraine) are less accurate, but Bulgarian data provide an age of ~400 ± 25 years BP. Archeomagnetic data from Germany [*Schnepp et al.*, 2003] show a younger date of the same feature at ~250 ± 25 years BP. The age dispersion of this apparently sharp inclination feature inside a relatively small territory could be due to dating errors. Alternatively real motion of the local (non-dipole) source of this short-lived (about 200–400 years) anomaly at the core-mantle boundary may account for the observed differences. The mean ages of the *I*2 or α feature for West Europe (~275 ± 75 years BP) and Lake Aral and Lake Aslikul data (~350 ± 25 years BP) differ by about ~50–100 years. This gives a westward drift rate of about ~0.5 ± 0.2°/year and would be consistent with other data about nondipolar

geomagnetic field changes [*Hongre et al.*, 1998]. Other inclination features of the Lake Aral and Lake Aslikul records (*i*3, *I*4, *i*5, *I*6) can easily be correlated. They have the same ages in both records. The ages of the same declination swings recorded in Lake Aral and Lake Aslikul, however, are different. Generally, declination swings in Lake Aslikul for which a ^{14}C age is available with 550 ± 70 years BP at a depth of 0.80 m [*Nourgaliev et al.*, 2000], are 50–200 years older than in Lake Aral. These declination differences may provide a means to estimate the morphology of moving spatial features of the geomagnetic field.

[13] We consider the reliability of the PSV records from Lake Aral and Lake Aslikul to be different in different time intervals. The more or less stable, but relatively low (~1 mm/year) sedimentation rate in Lake Aslikul without any visible gaps provides a stable and reliable PSV record for the last 1200 years. It appears to be smoothed compared to the modern data set and differences between sediment ages and NRM ages up to 50–100 years may occur. The sedimentation rate in Lake Aral changes abruptly prior to ~700 years BP and the directional noise level increases significantly (Figure 3). Beyond 1200 years BP the PSV signal becomes too noisy and fails reliability criteria because of sediment hardening (gypsum). The Lake Aral sediments, however, provide a very high resolution PSV record of high reliability (very small 95% confidence limits in Figure 3) for the interval between ~400–700 years BP. Being supported by the congruous Lake Aslikul PSV data, they provide fundamental data to extend (and also correct) the time interval of the historical field model [*Jackson et al.*, 2000] back to 1200 years BP.

[14] The high resolution PSV data of the last ~12 centuries seem to be controlled by more or less regular secular variation with periods of about 200–400 years and amplitudes of ~10–15° that are drifting on the Earth's surface with quite high rate of motion. Since they mirror parts of the magnetohydrodynamic processes in the outer core, their detailed analysis will provide new information about these processes.

5. Conclusion

[15] A paleomagnetic record of geomagnetic paleosecular variation during the last ~1200 years has been obtained from 2 sediment cores from the north part of Lake Aral (Kazakhstan). The cored sediment thickness of 6 m covers a maximum time interval from modern time to about 1500 years BP. Magnetic susceptibility and NRM intensity have been used for correlation between cores and for reconstruction of a composite core data set. The main swings and fine details of NRM declination and inclination records also correlate well between both lake cores. A very high sedimentation rate (up to 25 mm per year) provides a very high resolution PSV record for the interval from 450 ± 100 years BP to 655 ± 65 years BP . A time-scale has been developed based on eight AMS radiocarbon age determinations of organic matter. The results compare well with PSV records from next nearest Lake Aslikul in Bashkiriya [*Nourgaliev et al.*, 1996, 2000] and suggest that a 200–400 years secular variation period with amplitudes in declination and inclination up to 10–15° existed regularly during the time interval 0–1200 years BP. Amplitudes of the PSV record in the Lake Aral sediments are not reduced and smoothed by postdetrital magnetization processes. In the uppermost part, they correlate well with the historical geomagnetic model [*Jackson et al.*, 2000] and could be used down-core as regional master PSV for the last ~1200 years.

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G. Bonani and I. Hajdas, Institut für Teilchenphysik, ETH Hönggerberg, CH-8093 Zürich, Switzerland.
A. S. Borisov, P. G. Iassonov, and D. K. Nourgaliev, Paleomagnetic Laboratory, Faculty of Geology, Kazan State University, 18, Kremlyevskaya St., Kazan, 420008, Russia. (danis.nourgaliev@ksu.ru)
F. Heller, Institut für Geophysik, ETH-Hönggerberg, CH-8093 Zürich, Switzerland. (heller@mag.ig.erdw.ethz.ch)
H. Oberhänsli, Geoforschungszentrum Potsdam, Telegraphenberg, D-14473 Potsdam, Germany. (oberh@gfz-potsdam.de)