APWP-online.org User Manual

❖ Introducing APWP-online.org

What is APWP-online.org?

APWP-online.org is an online and open-source environment that provides user-friendly tools to determine relative paleomagnetic displacements (RPDs) and to compute apparent polar wander paths (APWPs) from site-level paleomagnetic data, following the statistical approaches recently developed by Vaes et al. (2022, 2023). In addition, APWP-online.org hosts the curated paleomagnetic database used to compute the most recent global APWP for the last 320 Ma (Vaes et al., 2023) and includes an interface for adding new high-quality paleomagnetic data that may be used for future iterations of the global APWP. For more details on APWP-online and the scientific background, please see the accompanying paper: https://doi.org/10.31223/X5WD44.

Aims of APWP-online.org

The main aim of APWP-online.org is to enable specialist users to apply state-of-the-art methods for computing apparent polar wander paths and tectonic displacements, which may contribute to solving detailed tectonic or paleogeographic problems. These tools allow the application of these computationally more complex methods – which are not (yet) integrated in existing software – to custom-made compilations of paleomagnetic data. The second aim of APWP-oneline.org is to provide a platform for the continuous improvement of the global APWP for the last 320 Ma, as well as the paleomagnetic database and plate circuit that underlie its computation. Paleomagnetists are invited to submit new, high-quality paleomagnetic data, or recommend modification of the existing database (e.g., the revision of age constraints) through the query form included in this portal, such that the global APWP can be regularly updated in the future.

APWP-online.org development

APWP-online.org is developed by a Dutch team consisting of two Earth scientists (Dr. Bram Vaes and Prof. Douwe van Hinsbergen) and a professional software developer (Joren Paridaens). Updates to APWP-online.org can be viewed on the *About page*, where changes, bug fixes, and new functionalities are tracked in the changelog. See below for more information on the code and data availability.

❖ Using APWP-online.org

Homepage

When you navigate to APWP-online.org in your web browser, you will arrive at the homepage. The homepage shows the navigation bar and provides an overview of three main portals of the website: the *APWP tool*, *RPD tool*, and the *Reference database*, as well as a link to the *About page*.

Data input

The *APWP* and *RPD tools* both require a single input file (as .xlsx. or .csv) containing a compilation of paleomagnetic poles and associated parameters, like age, sampling location, statistical parameters, etc. A user-provided input file can be uploaded from your local machine to the web application by clicking on the 'Add your dataset' button (Fig. 1a). The demo data of northeast and southwest Japan can be loaded using the 'Load in demo data'. Upon uploading a data file, a box appears that shows the name of the file, the number of paleopoles it contains, and a map plot of the sampling locations (with age entry indicated by its age). Pressing the 'hamburger' button opens a small menu where the user can download the example input file, export all datasets to a single text file, or remove all currently active datasets (Fig. 1b). A dataset can be activated for the application of the tools by pressing 'Use this set' and will then by highlighted in green.

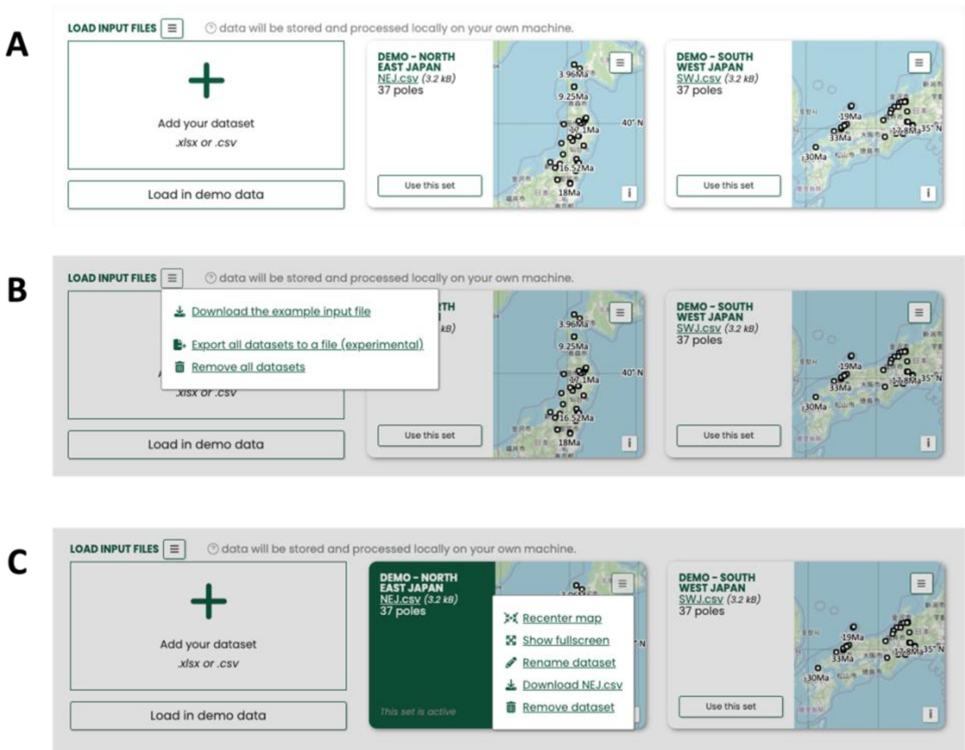

Fig. 1. A) Interface for uploading the file used as input for both the *APWP* and *RPD tools*. The demo data has been loaded after pressing the 'Load in demo data' button. B) Additional options are available under the 'hamburger' button (see text above). C) Example of an activated dataset. The 'hamburger' menu provides several useful functionalities such as the renaming or removal of the dataset.

It is important to emphasize that the existing structure of the input file should <u>not be modified</u>. Other columns may be added to the file, but the current column names should be preserved for the tools to work. Not all columns contain required input, see Fig. 2 for the columns with required input. If the age uncertainty range is not specified, the algorithm will automatically assign a ±2 Ma age uncertainty to that entry. In cases where the position of the paleopole is not provided, the mean paleomagnetic direction and sampling location are used to compute the paleopole longitude (*plon*) and latitude (*plat*). For expert users that aim to propagate the uncertainty elongation-inclination (E/I) method of Tauxe & Kent (2004) used to correct for sedimentary inclination shallowing, the lithology should be defined as 'sedimentary', and a flattening factor (*f*) and computed standard deviation of the uncertainty in the co-latitude of the shallowing-corrected paleomagnetic pole (*p_std*) should be added to the respective rows. See section 3 in Vaes et al. (2023) for more details.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	name	age	min_age	max_age	slat	slon	N	K	A95	plat	plon	mdec	minc	plateID	lithology	f	p_std
2	NEJ-Baba-RY	16.52	15.7	17.34	38	140.7	99	34.1	2.5	68.5	56.4	332.8	56.4		undefined		
3	NEJ-Baba-TA	14.44	13.56	15.32	38	140.7	93	16.6	3.7	73.5	331.9	356.6	38.6		undefined		
4	NEJ-Hir-Fuk1	22.3	21.6	23	37.3	140.6	4	90.3	9.7	77.7	36.2	345.7	52.8		undefined		
5	NEJ-Hir-Nii1	12.9	12.2	13.6	37.8	138.8	6	132.2	5.8	82.3	272.6	6.6	51.6		undefined		
6	NEJ-Hir-NMS	15	14.5	15.5	37.5	139.1	28	221.3	1.8	66.9	31.2	335.1	46.4		undefined		
7	NEJ-Hoshi98-KE	17.1	16.8	17.4	40.18	141.31	8	105.9	5.4	88.9	217.2	1.4	59.6		undefined		
8	NEJ-Hoshi98-NIS	21	20.7	21.3	40.28	141.33	40	41.6	3.5	34	54.2	295.8	40.6		undefined		
9	NEJ-Hoshi97-Mot	18	17.6	18.4	36.6	140.2	25	72.8	3.4	82.7	318.1	0.3	48.3		undefined		
10	NEJ-Hoshi97-Yam	17.2	16.8	17.6	36.6	140.2	33	21.6	5.5	81	235.1	11	54.8		undefined		

Fig. 2. View of the first 10 rows of the template input file opened in Microsoft Excel. Each entry – corresponding to a single paleomagnetic pole - is labelled in the output figures with its name and age (in Ma). Required input field are shown in green.
Abbreviations: min_age/max_age = lower and upper boundaries of age uncertainty range (in Ma); slat/slon = latitude and longitude of (mean) sampling location; N = number of paleomagnetic sites used to compute the paleopole; K = Fisher (1953) precision parameter of the distribution of virtual geomagnetic poles (VGPs); A95 = radius of the 95% confidence circle about the paleopole; plat/plon = paleopole latitude and longitude; mdec/minc = mean declination and inclination; plateID = plate identification number, f = flattening factor (*only for sedimentary data*), p_std = standard deviation of the assumed normal distributed co-latitudes, obtained from the E/I correction (*only for sedimentary data*).

Data storage and sharing

All processing of paleomagnetic data and calculations are performed locally on the machine of the user. No imported data or results are stored externally on a server or sent over the internet, ensuring the integrity of the data and user. The input data and results are instead stored locally within the local storage of the browser, and thus allow the user to continue using the tools offline. The local storage may also be downloaded through the 'Download session' button on the *About page*, enabling users to continue working with the input data and results at any later moment by re-uploading this file.

APWP tool

The APWP tool allows users to compute an apparent polar wander path (APWP) based on (simulated) site-level paleomagnetic data, using the approach of Vaes et al. (2023). This tool can be used to construct an APWP for any plate or terrane regardless of the age of rocks from which the data are derived, as long as the input data are provided in the coordinate system of the same plate or terrane. To compute the APWP, the user first needs to specify the age range for the APWP, the size of the time window and the time step at which the reference poles of the APWP are computed (Fig. 3). Prior to initializing the APWP tool, the user can also choose the number of iterations used for the computation of the path and the estimation of its 95% confidence region. It is important to note that a larger number of iterations will significantly slow down the computation time.

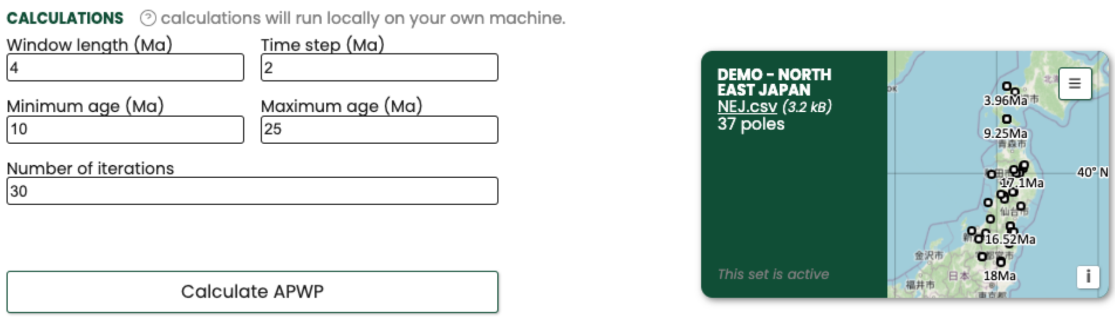

Fig. 3. User interface for the application of the *APWP tool* to a selected dataset. Here, the size of time window and time step for the APWP can be chosen, as well as the age range for which the APWP will be computed. Please note that when there is no data whose age range overlaps with a specific time window, the algorithm will not provide an estimate of the reference pole of the APWP.

During computation of the APWP a pop-up window appears that shows the progress of the calculation. The total computation time is provided above the output figure, which may help to user to choose an optimal number of iterations as well as to estimate the total computation time when increasing the number of iterations. It is strongly recommended to use a low number of iterations first, while testing different window lengths and time steps. The computed APWP is plotted on a map showing the mean age of each reference pole and its 95% confidence region (Fig. 4). The output file (.xlsx format) containing the APWP and associated statistical parameters can be downloaded using the button on the top right. After computing a custom APWP using this tool, the resulting APWP can be automatically used in the relative paleomagnetic displacement (RPD) tool that is described below.

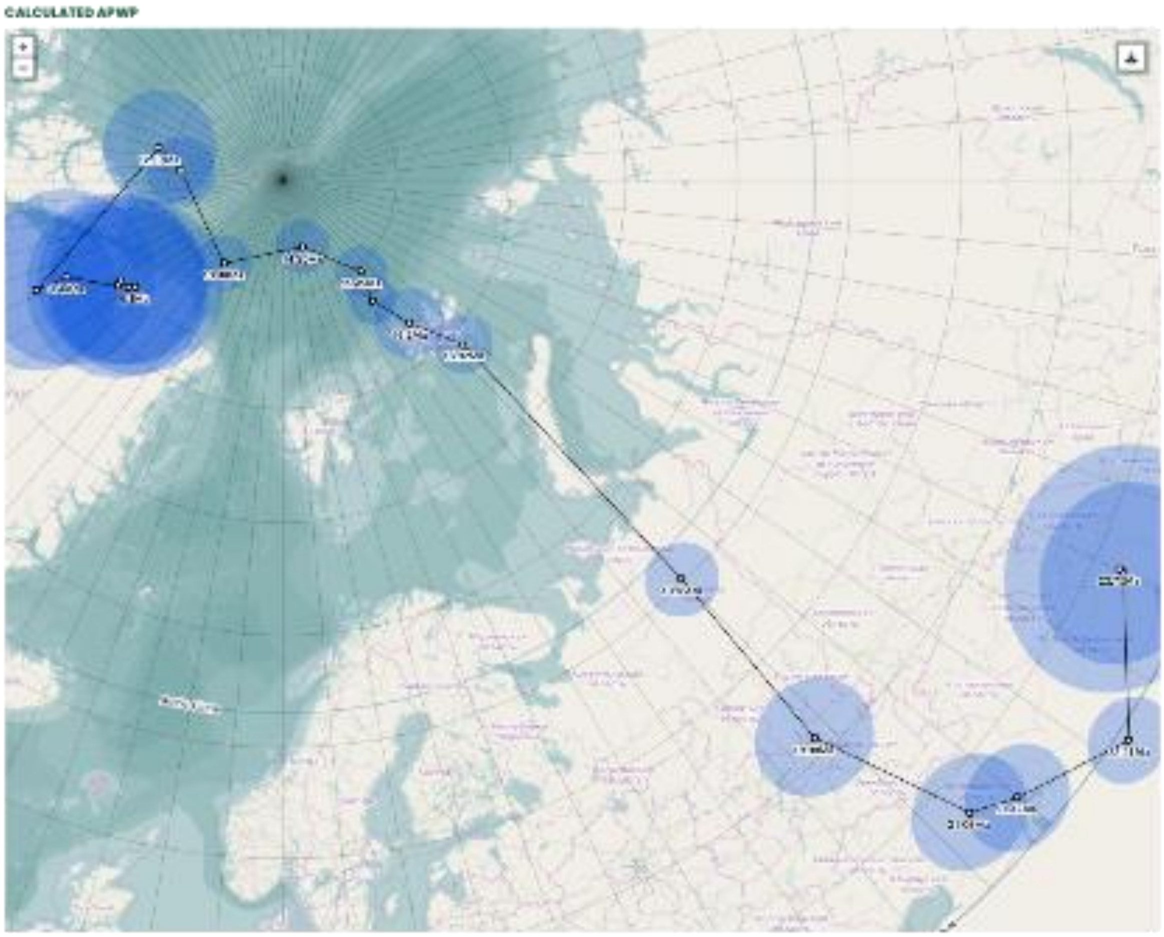

Fig. 4. Output figure showing the computed APWP plotted on a map projection. The path (black line) connects the reference poles of the APWP that are shown with white circle and their 95% confidence regions (P_{95}, in blue). The age indicates the mean age of the re-sampled VGPs that fall within the time window used to compute that reference pole position.

	A	B	C	D	E	F	G	H	I	J	K	L
1	age	min_age	max_age	center_age	plat	plon	P95	N	elong	mean_E	mean_K	mean_csd
2	10.2670434	8	12	10	78.1360379	298.216299	5.12370384	46.7666667	1.34216343	1.61825922	21.5402446	17.6488265
3	12.9878851	10	14	12	85.7364754	240.906697	2.19355162	174.866667	1.61370453	2.07952728	19.59689	18.3282981
4	14.6875298	12	16	14	87.6743554	0.25952556	1.42799868	462.7	1.42875044	1.27851041	15.9800279	20.277497
5	15.9685865	14	18	16	82.3935316	46.3834134	1.24887569	599.4	2.80473046	1.77147993	14.1456904	21.5461272
6	17.0492821	16	20	18	76.82583	56.5786181	1.50332486	327.5	1.34847795	2.44855528	13.0697948	22.4302164
7	20.2760566	18	22	20	51.2378237	52.5252722	2.66964318	135.833333	1.74516163	2.10525192	9.61196188	26.1648598
8	21.5780198	20	24	22	46.029444	62.3407757	2.47269599	138.333333	1.64781636	1.63562001	10.21886	25.3770135
9	23.4964196	22	26	24	48.6087639	75.7471099	4.84195899	66.1666667	2.77317995	1.79774253	10.9143703	24.6030757
10	24.9642858	24	28	26	46.0737592	77.4582215	6.46654271	20.0666667	2.1067034	2.30760185	20.837532	18.0545725

Fig. 5. View of the first 10 rows of the output file of the *APWP tool* opened in Microsoft Excel. Each entry corresponds to a reference pole of the APWP, indicated by its mean age (that is, the average age of the re-sampled VGPs that fall within the time window).

Abbreviations: min_age/max_age = lower and upper boundaries of the time window centered around the center_age (in Ma); N and P95 are the average number of re-sampled VGPs that fall within the time window and the 95% confidence region of the reference pole (in degrees); elong = the elongation of the distributions of the simulated reference poles (where the total number equals the number of iterations); mean_E, mean_K and mean_csd are the average elongation, Fisher (1953) precision parameter, and circular standard deviation of the re-sampled VGPs.

RPD tool

The relative paleomagnetic displacement (RPD) tool allows the determination of a displacement of a tectonic terrane or plate relative to certain reference, using the comparison metric introduced by Vaes et al. (2022). Central to this approach is the comparison between an observed paleopole and a reference pole in which the number of paleomagnetic sites used to compute the paleopole is taken into consideration. To compute the relative displacements, quantified as vertical-axis rotations and paleolatitudinal displacements, the user can choose an input dataset and a reference. The input dataset can be a compilation of paleopoles *or* a custom APWP earlier computed with the APWP tool (see paper for more details). As a reference, the global APWP of Vaes et al. (2023) can be used in the coordinates of a major plate, the geographic pole, or a custom dataset.

For the computation of the RPDs in the RPD tool, the user may specify a few input parameters, similar to the APWP tool (Fig. 6). The number of iterations and time window (default is 10 Ma) used to compute the reference pole position and its uncertainty (the B_{95}) can be provided as direct input on-screen. Instead of using the sampling location of each entry in the input file, a reference location may instead be chosen by the user or determined from the input directly (Fig. 6). Note that specifying a reference location is required when using a custom APWP as input for this tool.

The user may choose the reference against which the uploaded input data are compared. Absolute declination and paleolatitude values may be computed by choosing the spin axis as a reference. In most cases, the reference will be provided by the global APWP of Vaes et al. (2023). Alternatively, the user may use a custom reference database uploaded in the *RPD tool*, allowing the determination of RPDs using reference poles computed from this database. Again, it is important to note that a larger number of iterations will lead to much longer computation times.

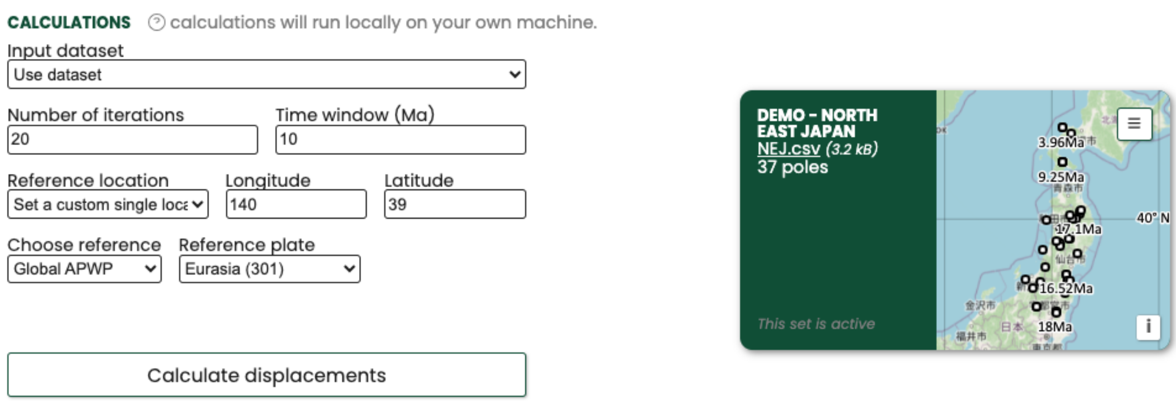

Fig. 6. User interface for the application of the *RPD tool* to a selected dataset. Here, the type of input dataset can be chosen (an input dataset or previously computed APWP), as well as the number of iterations and time window (default is 10 Ma). In addition, the reference location and reference against which the RPDs are calculated should be specified.

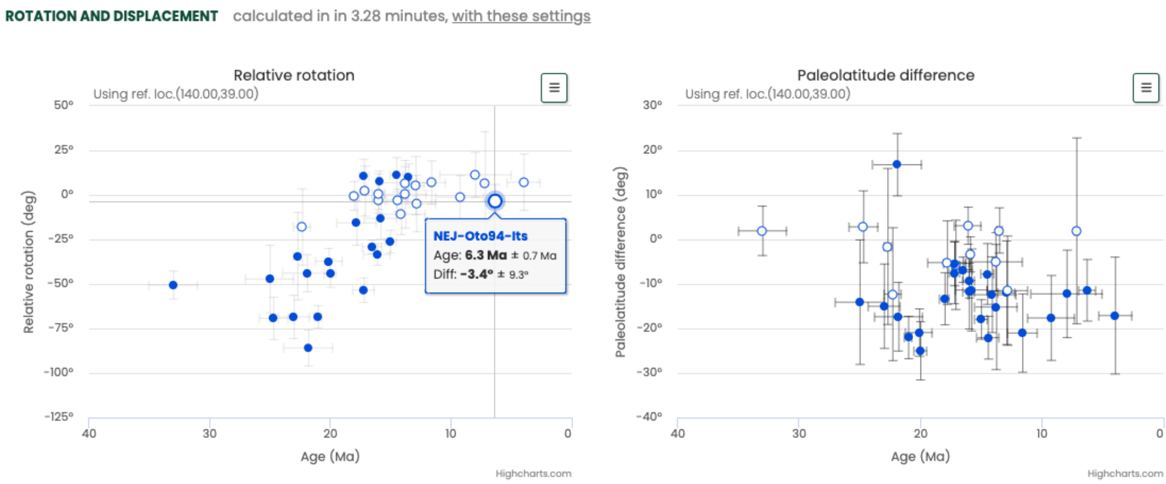

Fig. 7. Output figures showing the relative rotation and paleolatitudinal difference between each paleomagnetic pole in the northeast Japan compilation versus Eurasia. White circles indicate data points that are not statistically significant different from zero. Errors bars indicate the age uncertainty range and 95% confidence regions. Hoovering over specific data points show the name, age and computed relative rotation or paleolatitudinal difference.

The output of the *RPD tool* consists of two figures on the web interface that show the relative vertical-axis rotations and paleolatitudinal displacement computed for each input paleopole, which can be downloaded as raster (PNG) or vector (SVG and PDF) image. As for the *APWP tool*, the output results may also be downloaded as an Excel file.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	name	age	min_age	max_age	N	R	delta_R	R_sig	L	delta_L	L_sig	ref_plon	ref_plat	A95	B95	plat	plon
2	NEJ-Baba-RY	16.52	15.7	17.34	99	-27.615787	3.1776593	TRUE	-0.8964083	2.5	FALSE	0	90	2.5	0	68.4674532	56.3778989
3	NEJ-Baba-TA	14.44	13.56	15.32	93	-3.6369316	4.01383595	FALSE	-16.209117	3.7	TRUE	0	90	3.7	0	73.4972982	331.880775
4	NEJ-Hir-Fuk1	22.3	21.6	23	4	-14.648902	11.8901132	TRUE	-3.8621159	9.7	FALSE	0	90	9.7	0	77.7066824	36.2446384
5	NEJ-Hir-Nii1	12.9	12.2	13.6	6	6.83203449	6.96444523	FALSE	-5.4527779	5.8	FALSE	0	90	5.8	0	82.2541469	272.64169
6	NEJ-Hir-NMS	15	14.5	15.5	28	-25.026759	2.05345644	TRUE	-10.236606	1.8	TRUE	0	90	1.8	0	66.9435196	31.2454815
7	NEJ-Hoshi98-KE	17.1	16.8	17.4	8	1.38318492	6.97858575	FALSE	0.23444375	5.4	FALSE	0	90	5.4	0	88.9015488	217.240879
8	NEJ-Hoshi98-NIS	21	20.7	21.3	40	-64.357787	3.81888	TRUE	-15.435085	3.5	TRUE	0	90	3.5	0	34.0460429	54.2264657
9	NEJ-Hoshi97-Mot	18	17.6	18.4	25	0.27762619	3.99707346	FALSE	-7.300223	3.4	TRUE	0	90	3.4	0	82.6962779	318.141664
10	NEJ-Hoshi97-Yam	17.2	16.8	17.6	33	11.336006	6.95323044	TRUE	-1.3471894	5.5	FALSE	0	90	5.5	0	81.0116561	235.064014
11	NEJ-Hoshi13	15.9	15.7	16.1	106	8.62464928	3.24349188	TRUE	3.258178	2.4	TRUE	0	90	2.4	0	82.6932091	200.771492
12	NEJ-Hoshi07	13.5	13.3	13.7	82	11.6269352	3.60501501	TRUE	9.24214652	2.4	TRUE	0	90	2.4	0	77.5270915	178.422719
13	NEJ-Hos-Im	16.1	15	17.2	51	-32.338841	3.93048863	TRUE	9.56367518	2.6	TRUE	0	90	2.6	0	65.003351	83.0960516
14	NEJ-Hos-Kr	14.5	14	15	19	9.93118851	3.78900088	TRUE	-1.3710125	3	FALSE	0	90	3	0	82.0923273	236.870609
15	NEJ-Oto85-Dai	20.1	19	21.2	17	-32.468227	4.22493863	TRUE	-13.102538	3.8	TRUE	0	90	3.8	0	59.8471742	34.029832

Fig. 8. View of the output file of the *RPD tool* opened in Microsoft Excel. Each entry corresponds to a paleomagnetic pole, for which the vertical-axis rotation and paleolatitudinal displacement relative to the chosen reference is computed.
Abbreviations of columns not yet defined in the input file (see Fig. 2): R/delta_R = relative rotation and 95% uncertainty in degrees; L/delta_L = paleolatitudinal displacement and 95% uncertainty in degrees; R_sig/L_sig = indicates whether difference is statistically significant; ref_plon/ref_plat = longitude and latitude of the reference pole used to compute the RPDs, B_{95} = uncertainty of reference pole weighted against the number of sites (N) included in the input paleopole.

Reference database

The *Reference database* portal hosts the paleomagnetic database that underpins the global APWP for the last 320 Ma from Vaes et al. (2023). At this portal, the most recent version of the global APWP – in the coordinate frame of all major tectonic plates - can be accessed and downloaded, as well as the paleomagnetic database and the global plate circuit, which underlie the computation of the APWP. This portal provides a platform where future updates of the global APWP will be made available.

Researchers are encouraged to submit new high-quality paleomagnetic data obtained from stable plate interiors – after publication in a peer-reviewed journal – that may be included in the database. We also welcome new age data that provides better constraints on the rock and/or magnetization age of the paleomagnetic data that is included in the database. New data and corrections to existing data can be provided by sending an email to info@apwp-online.org.

❖ Further information

Code and data availability

The APWP-online.org application can be freely accessed with the latest versions of commonly used internet browsers, such as Google Chrome, Mozilla Firefox, and Safari. The latest version of the source codes of the webtools and the Python scripts that are used to perform the calculations are available on Github, see the *About* page. APWP-online.org is an open-source web application licensed under the GNU General Public License v3.0.

Contact

For any questions about APWP-online.org, contact us at info@apwp-online.org

Background literature

Fisher, R. A. (1953). Dispersion on a sphere. Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences, 217(1130), 295-305.

Tauxe, L., & Kent, D. V. (2004). A simplified statistical model for the geomagnetic field and the detection of shallow bias in paleomagnetic inclinations: was the ancient magnetic field dipolar? Geophysical Monograph Series, 145, 101-155.

Vaes, B., Gallo, L. C., & van Hinsbergen, D. J. (2022). On pole position: causes of dispersion of the paleomagnetic poles behind apparent polar wander paths. Journal of Geophysical Research: Solid Earth, 127(4), e2022JB023953.

Vaes, B., van Hinsbergen, D. J., van de Lagemaat, S. H., van der Wiel, E., Lom, N., Advokaat, E. L., ... & Langereis, C. G. (2023). A global apparent polar wander path for the last 320 Ma calculated from site-level paleomagnetic data. Earth-Science Reviews, 104547.