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| **Table S4.** Summary of the paleoelevation results from the Himalayan-Tibetan orogen |
| Map ID | Locality | Age (Ma) | Paleoelevation (m) | Method | Data source |
| **Stage 1 (65-54 Ma and thereafter)** |
| **Himalayas** |
| 5 | Liuqu | ~56 | 919 | CLAMP | Ding et al., 2017 |
| **Lhasa** |
| 8 | Linzhou | 60-50 | 4500±450 | δ18Oc of paleosols | Ding et al., 2014 |
| 10 | Tangrayum Co | 46 | 2590+730/-910 | δ18Oc of paleosols | Xu et al., 2015 |
| **Qiangtang** |
| 13 | Heihuling | 50-28 | 5200±600 | δ18Oc of paleosols | Xu et al., 2013 |
| 15 | Gonjo | 54-50 | ~700 | carbonate clumped isotope | Xiong et al., 2020 |
| **Songpan-Ganzi** |
| 18 | Tuotuohe | 52-30 | <2000 | δ18Oc of carbonates | Cyr et al., 2005 |
| 55-35 | ~4000 | δ18Oc of carbonates | Quade et al., 2011 |
| 55-35 | 2000-2600 | δD of n-alkane | Polissar et al., 2009 |
| **NE Tibetan Plateau** |
| 20 | Hero hill | 49-22 | 1462+148/-227 | δ18Oc of mammalian fossils, δ18Oc of carbonates | Li L et al., 2017 |
| **Stage 2 (43-39 Ma and thereafter)** |
| **Lhasa** |
| 12 | Lunpola | ~39.5 | <2300 | fossil palm leaves | Su et al., 2019; Xiong et al., 2022 |
| **Qiangtang** |
| 14 | Nangqian | ~43-33 | <3000 | magmatism | Zhang et al., 2020 |
| 15 | Gonjo | 44-40 | ~3800 | carbonate clumped isotope | Xiong et al., 2020 |
| 16 | Markam | ~37 | 3837+1180/-1574 | δ18Oc of carbonates | Li S Y et al., 2015 |
| 17 | Liming | ~37 | 2700±300 | δ18Oc of carbonates | Hoke et al., 2014 |
| **NE Tibetan Plateau** |
| 23 | Longmori | 40.2-35.3 | 2180-3502 | δ18Oc and δ13Cc of lacustrine | Qi et al., 2015 |
| **Stage 3 (34-29 Ma and thereafter)** |
| **Lhasa** |
| 11 | Nima | ~26 | 4500-4700 | δ18Oc of paleosols | DeCelles et al., 2007a |
| 12 | Lunpola | 29-26 | 4260+475/-575 | δ18Oc of carbonates | Rowley and Currie, 2006; Fang et al., 2020; Xiong et al., 2022 |
| 4500-4900 | δD of n-alkane | Polissar et al., 2009 |
| 26-23 | 2770±530 | δD of n-alkane | Jia et al., 2015 |
| **Songpan-Ganzi**  |
| 18 | Tuotuohe | ~35 | 2000 | Fossil pollens | Miao et al., 2015 |
| ~36-30 | 4000 | leaf wax δ2H | Lin et al., 2020 |
| **NE Tibetan Plateau** |
| 21 | Dahonggou | 30.8 | 3300 ±1400  | CLAMP | Song et al., 2020 |
| 24 | Xining | ~36 | 2000-3000 | Fossil pollens | Dupont-Nivet et al., 2008 |
| 26 | Lanzhou | 30-28 | 2000-3000 | Fossil pollens | Miao et al., 2013 |
| **Stage 4 (24-21 Ma and thereafter)** |
| **Lhasa** |
| 6 | Qiabulin | 21-19 | 2315 | CLAMP | Ding et al., 2017 |
| 24-21 | ~2000 | δ18Oc of carbonates | Xu et al., 2018 |
| 21-19 | ~4100 |
| 9 | Kailash | ~24 | 4700-6700 | δ18Oc of paleosols | DeCelles et al., 2011 |
| ~20-19 | ~4900 | δ18Oc of carbonates | Xu et al., 2018 |
| 12 | Lunpola | 23 | 3000-3200 | Fossil pollens | Sun et al., 2014 |
| **Songpan-Ganzi** |
| 19 | Wudaoliang | ~23 | 4000-4200 | δD of n-alkane | Polissar et al., 2009 |
| ~19 | 1300-2900 | Fossil leaves | Sun et al., 2015 |
| **NE Tibetan Plateau** |
| 20 | Hero hill | 22-8.1 | 1496+153/-234 | δ18Oc of mammalian fossils, δ18Oc of carbonates | Li L et al., 2017 |
| 23 | Sulixiang | 22.7-18.2 | ~2848 | δ18Oc and δ13Cc of lacustrine | Qi et al., 2015 |
| **Stage 5 (16-15 Ma and thereafter)** |
| **Himalayas** |
| 4 | Qomolangma | ~17 | 5100-5400 | δD of hydrous minerals | Gebélin et al., 2013 |
| **Lhasa** |
| 7 | Namling | 15 | 5200+1370/-605 | δ18Oc of paleosols | Currie et al., 2005 |
| 4689±895 | CLAMP | Spicer et al., 2003 |
| 4638±847 | Khan et al., 2014 |
| 5400±728 |
| Mahasin et al., 2014 |
| 5100＋1300/-1900 | δD of n-alkane | Currie et al., 2016 |
| 12 | Lunpola | 18-16 | ~3000 | Mammalian fossils | Deng et al., 2012 |
| **NE Tibetan Plateau** |
| 22 | Huaitoutala | 10~15 | 3300-4000 | leaf wax δ2H | Zhuang et al., 2014 |
| ~12.4 | >700-1100 | soil tetraethers | Zhuang et al., 2019 |
| 23 | Sulixiang | 18.2-13.2 | ~3586 | δ18Oc andδ13Cc of lacustrine | Qi et al., 2015 |
| 26 | Zeku | 19-<16 | 1200-1400 | Fossil pollens | Hui et al., 2018 |
| **Stage 6 (11-3 Ma)** |
| **Himalayas** |
| 1 | Zhada | 9 | 5400±500 | T(△47) of carbonates | Huntington et al., 2015 |
| ~9 | 5600±300 | δ18Oc of fossil shells | Saylor et al., 2009 |
| ~4 | 4000±300 | δ18Oc of fossil shells | Murphy et al., 2009 |
| 2 | Thakkhola | ~7 | 4500-6300 | δ18Oc of paleosols | Garzione et al., 2000a |
| 5700+1410/-730 | δ18Oc of paleosols | Rowley et al., 2001 |
| ~11 | 3800-5900 | δ18Oc of paleosols | Garzione et al., 2000a, b |
| 6240+1410/-870 | δ18Oc of paleosols | Rowley et al., 2001 |
| 3 | Gyirong | >7 | <2900-3400 | δ13Cc of fossil teeth | Wang et al., 2006 |
| 6700±700 | δ18Oc of mammalian fossils | Xu et al., 2010 |
| 5850+1410/-730 | δ18Oc of mammalian fossils | Rowley et al., 2001 |
| 7-3.2 | <2300 | GDGTs | Chen et al., 2020 |
| **NE Tibetan Plateau** |
| 20 | Hero hill | 8.1-2.5 | 2084+247/-354 | δ18Oc of mammalian fossils, δ18Oc of carbonates | Li L et al., 2017 |
| <2.5 | 2476+321/-445 |
| 24 | Xining | ~10.5-8 | 1500-1800 | GDGTs | Chen et al., 2019 |
| *Note.* N= reference number and Map ID in Fig.1, represents the different locations referred in different literatures. |

**REFERENCES CITED**

Chen, C., Bai, Y., Fang, X., Guo, H., Meng, Q., Zhang, W., Zhou, P., & Murodov, A. (2019). A late miocene terrestrial temperature history for the northeastern Tibetan plateau's period of tectonic expansion. *Geophysical Research Letters*, *46*(14), 8375-8386. <https://doi.org/10.1029/2019GL082805>.

Chen, C., Bai, Y., Fang, X., Xu, Q., Zhang, T., Deng, T., He, J., & Chen, Q. (2020), Lower-altitude of the Himalayas before the mid-Pliocene as constrained by hydrological and thermal conditions. *Earth and Planetary Science Letters*, *545*, 116422. <https://doi.org/10.1016/j.epsl.2020.116422>.

Currie, B. S., Rowley, D. B., & Tabor, N. J. (2005). Middle Miocene paleoaltimetry of southern Tibet: Implications for the role of mantle thickening and delamination in the Himalayan orogen. *Geology*, *33*(3), 181-184, <https://doi.org/10.1130/G21170.1>.

Currie, B. S., Polissar, P. J., Rowley, D. B., Ingalls, M., Li, S., Olack, G., & Freeman, K. H. (2016). Paleoaltimetry of the Early Miocene-Pliocene Oiyug basin, southern Tibet. *American Journal of Science*, *316*, 401-436, <https://doi.org/10.2475/05.2016.01>.

Cyr, A. J., Currie, B. S., & Rowley, D. B. (2005). Geochemical Evaluation of Fenghuoshan Group Lacustrine Carbonates, North-Central Tibet: Implications for the Paleoaltimetry of the Eocene Tibetan Plateau. *Journal of Geology*, *113*(5), 517-533. <https://doi.org/10.1086/431907>.

Decelles, P. G., Quade, J., Kapp, P., Fan, M., Dettman, D. L., & Ding, L. (2007). High and dry in central tibet during the late Oligocene. *Earth and Planetary Science Letters*, *253*(3-4), 389-401. <https://doi.org/10.1016/j.epsl.2006.11.001>.

DeCelles, P. G., Kapp, P., Quade, J., & Gehrels, G. E. (2011), Oligocene-Miocene Kailas basin, southwestern Tibet: Record of postcollisional upper-plate extension in the Indus-Yarlung suture zone. *Geological Society of America Bulletin*, *123*(7-8), 1337-1362. <https://doi.org/10.1130/B30258.1>.

Deng, T., Wang, S., Xie, G., Li, Q., Hou, S., & Sun, B. (2012). A mammalian fossil from the dingqing formation in the lunpola basin, northern Tibet and its relevance to age and paleo-altimetry. *China Science Bulletin*, *57*(2), 261-269. <https://doi.org/10.1007/s11434-011-4773-8>.

Ding, L., Xu, Q., Yue, Y., Wang, H., Cai, F., & Li, S. (2014). The Andean-type Gangdese Mountains: Paleoelevation record from the Paleocene-Eocene Linzhou Basin. *Earth and Planetary Science Letters*, *392*, 250-264. <https://doi.org/10.1016/j.epsl.2014.01.045>.

Ding, L., Spicer, R. A., Yang, J., Xu, Q., Cai, F., Li, S., Lai, Q., Wang, H., Spicer, T. E. V., Yue, Y., Shukla, A., Srivastava, G., Khan, M. A., Bera, S., & Mehrotra, R. (2017). Quantifying the rise of the Himalaya orogen and implications for the South Asian monsoon. *Geology*, *45*(3), 215-218. <https://doi.org/10.1130/G38583.1>.

Dupont-Nivet, G., Hoorn, C., & Konert, M. (2008). Tibetan uplift prior to the Eocene-Oligocene climate transition: Evidence from pollen analysis of the Xining Basin. *Geology*, *36*(12), 987-990. <https://doi.org/10.1130/0091-7613-37.6.506>.

Fang, X., Dupont-Nivet, G., Wang, C., Song, C., Meng, Q., Zhang, W., Nie, J., Zhang, T., Mao, Z., & Chen, Y. (2020). Revised chronology of central Tibet uplift (Lunpola Basin). *Science Advance*, *6*(50): eaba7298. <https://doi.org/10.1126/sciadv.aba7298>.

Garzione, C. N., Dettman, D. L., Quade, J., DeCelles, P. G., & Butler, R. F. (2000a). High times on the Tibetan Plateau: Paleoelevation of the Thakkhola graben, Nepal. *Geology*, *28*(4), 339-342. [https://doi.org/10.1130/0091-7613(2000)28<339:HTOTTP>2.0.CO;2](https://doi.org/10.1130/0091-7613%282000%2928%3C339%3AHTOTTP%3E2.0.CO;2).

Garzione, C. N., Quade, J., DeCelles, P. G., & English, N. B. (2000b). Predicting paleoelevation of Tibet and the Himalaya from δ18O vs. altitude gradients in meteoric water across the Nepal Himalaya. *Earth and Planetary Science Letters*, *183*(1-2), 215-229. [https://doi.org/10.1016/S0012-821X(00)00252-1](https://doi.org/10.1016/S0012-821X%2800%2900252-1).

Gebelin, A., Mulch, A., Teyssier, C., Jessup, M. J., Law, R. D., & Brunel, M. (2013). The Miocene elevation of Mount Everest. *Geology*, *41*(7), 799-802. <https://doi.org/10.1130/G34331.1>.

Hoke, G. D., Liu, Z., Hren, M. T., Wissink, G. K., & Garzione, C. N. (2014). Stable isotopes reveal high southeast Tibetan Plateau margin since the Paleogene. *Earth and Planetary Science Letters*, *394*, 270-278. <https://doi.org/10.1130/G34331.1>.

Huntington, K. W., Saylor, J., Quade, J., & Hudson, A. M. (2015). High late Miocene-Pliocene elevation of the Zhada Basin, southwestern Tibetan Plateau, from carbonate clumped isotope thermometry. *Geological Society of America Bulletin*, *127*(1-2), 181-199. <https://doi.org/10.1130/B31000.1>.

Hui, Z., Li, X., Ma, Z., Xiao, L., Zhang, J., & Chang, J. (2018). Miocene pollen assemblages from the Zeku Basin, northeastern Tibetan Plateau, and their palaeoecological and palaeoaltimetric implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *511*, 419-432. <https://doi.org/10.1016/j.palaeo.2018.09.009>.

Jia, G., Bai, Y., Ma, Y., Sun, J., & Peng, P. (2015). Paleoelevation of Tibetan Lunpola basin in the Oligocene-Miocene transition estimated from leaf wax lipid dual isotopes. *Global Planetary Change*, *126*, 14-22, <https://doi.org/10.1016/j.gloplacha.2014.12.007>.

Khan, M. A., Spicer, R. A., Bera, S., Ghosh, R., Yang, J., and Spicer, T. E. V., Guo, S., Su, T., Jacques, F., & Grote, P. J. (2014). Miocene to Pleistocene floras and climate of the Eastern Himalayan Siwaliks, and new palaeoelevation estimates for the Namling–Oiyug Basin, Tibet. *Global Planetary Change*, *113*, 1-10. <https://doi.org/10.1016/j.gloplacha.2013.12.003>.

Li, L., Wu, C., Fan, C., Li, J., & Zhang, C. (2017). Carbon and oxygen isotopic constraints on paleoclimate and paleoelevation of the southwestern Qaidam basin, northern Tibetan Plateau. *Geoscience Frontiers*, *8*(5), 1175-1186. <https://doi.org/10.1016/j.gsf.2016.12.001>.

Li, S., Currie, B. S., Rowley, D. B., & Ingalls, M. (2015). Cenozoic paleoaltimetry of the SE margin of the Tibetan Plateau: Constraints on the tectonic evolution of the region. *Earth and Planetary Science Letters*, *432*, 415-424. <https://doi.org/10.1016/j.epsl.2015.09.044>.

Lin, J., Dai, J., Zhuang, G., Jia, G., Zhang, L., Ning, Z., Li, Y., & Wang, C. (2020). Late Eocene-Oligocene high relief paleotopography in the north central Tibetan Plateau: Insights from detrital zircon U-Pb geochronology and leaf wax hydrogen isotope studies. *Tectonics*, *39*(2), e2019TC005815. <https://doi.org/10.1029/2019TC005815>.

Mahasin, A. K., Spicer, R. A., Subir, B., Ruby, G., Yang, J., Teresa, E. V., Shuang, X., Tao S., Frédéric, J., & Paul, J. G. (2014). Miocene to Pleistocene floras and climate of the Eastern Himalayan Siwaliks, and new palaeoelevation estimates for the Namling-Oiyug Basin, Tibet. *Global Planetary Change*, *113*, 1-10. <https://doi.org/10.1016/j.gloplacha.2013.12.003>.

Miao, Y., Wu, F., Herrmann, M., Yan, X., & Meng, Q. (2013). Late early Oligocene East Asian summer monsoon in the NE Tibetan Plateau: Evidence from a palynological record from the Lanzhou Basin, China. *Journal of Asian Earth Sciences*, *75*, 46-57. <https://doi.org/10.1016/j.jseaes.2013.07.003>.

Murphy, M. A., Saylor, J. E., & Ding, L. (2009). Late Miocene topographic inversion in southwest Tibet based on integrated paleoelevation reconstructions and structural history. *Earth and Planetary Science Letters*, *282*(1-4), 1-9. <https://doi.org/10.1016/j.epsl.2009.01.006>.

Polissar, P. J., Freeman, K. H., Rowley, D. B., McInerney, F. A., & Currie, B. S. (2009). Paleoaltimetry of the Tibetan Plateau from D/H ratios of lipid biomarkers. *Earth and Planetary Science Letters*, *287*(1-2), 64-76. <https://doi.org/10.1016/j.epsl.2009.07.037>.

Qi, B., Hu, D., Yang, X., Zhang, X., & Zhao, X. (2015). Paleoelevation of the Qilian Mountain inferred from carbon and oxygen isotopes of Cenozoic strata. *Acta Geoscientica Sinica*, *36*(3), 322-331. <https://doi.org/10.3975/cagsb.2015.03.07>. (In Chinese with English abstract).

Quade, J., Breecker, D. O., Daeron, M., & Eiler, J. (2011). The paleoaltimetry of Tibet: An isotopic perspective. *American Journal of Science*, *311*(2), 77-115. <https://doi.org/10.2475/02.2011.01>.

Rowley, D. B., Pierrehumbert, R. T., & Currie, B. S. (2001). A new approach to stable isotope-based paleoaltimetry: implications for paleoaltimetry and paleohypsometry of the High Himalaya since the Late Miocene. *Earth and Planetary Science Letters*, *188*(1-2), 253-268. [https://doi.org/10.1016/S0012-821X(01)00324-7](https://doi.org/10.1016/S0012-821X%2801%2900324-7).

Rowley, D. B., & Currie, B. S. (2006). Palaeo-altimetry of the late eocene to miocene lunpola basin, central Tibet. *Nature*, *439*(7077), 677-681. <https://doi.org/10.1038/nature04506>.

Saylor, J. E., Quade, J., Dellman, D. L., DeCelles, P. G., Kapp, P. A., & Ding, L. (2009). The late Miocene through present paleoelevation history of southwestern Tibet. *American Journal of Science*, *309*(1), 1-42. <https://doi.org/10.2475/01.2009.01>.

Song, B., Spicer, R. A., Zhang, K., Ji, J., Farnsworth, A., Hughes, A. C., Yang, Y., Hang, F., Xu, Y., Spicer, T., Shen, T., Lunt, D. J., & Shi, G. (2020). Qaidam Basin leaf fossils show northeastern Tibet was high, wet and cool in the early Oligocene. *Earth and Planetary Science Letters*, *537*, 116175. <https://doi.org/10.1016/j.epsl.2020.116175>.

Spicer, R. A., Harris, N. B. W., Widdowson, M., Herman, A. B., Guo, S., Valdes, P. J., Wolfe, J. A., & Kelley, S. P. (2003). Constant elevation of southern Tibet over the past 15 million years. *Nature*, 421(6923), 622-624. <https://doi.org/10.1038/nature01356>.

Su, T., Farnsworth, A., Spicer, R. A., Huang, J., Wu, F., Liu, J., Li, S., Xing, Y., Huang, Y., Deng, W., Tang ,H., Xu, C., Zhao, F., Srivastava, G., Valdes, P. J., Deng, T., & Zhou, Z. (2019). No high Tibetan Plateau until the Neogene. *Science Adcances*, *5*(3), eaav2189. <https://doi.org/10.1126/sciadv.aav2189>.

Sun, B., Wang, Y., Li, C., Yang, J., Li, J., Li, Y., Deng, T., Wang, S., Zhao, M., Spicer, R. A., Ferguson, D. K., & Mehrotra., R. C. (2015). Early Miocene elevation in northern Tibet estimated by palaeobotanical evidence. *Scientific Reports*, *5*, 10379. <https://doi.org/10.1038/srep10379>.

Sun, J., Xu, Q., Liu, W., Zhang, Z., Xue, L., & Zhao, P. (2014). Palynological evidence for the latest Oligocene-early Miocene paleoelevation estimate in the Lunpola Basin, central Tibet. *Palaeogeography Palaeoclimatology Palaeoecology*, *399*, 21-30. <https://doi.org/10.1016/j.palaeo.2014.02.004>.

Wang, Y., Deng, T., & Biasatti, D. (2006). Ancient diets indicate significant uplift of southern Tibet after ca. 7 Ma. *Geology*, *34*(4), 309-312. <https://doi.org/10.1130/G22254.1>.

Xiong, Z., Ding, L., Spicer, R. A., Farnsworth, A., Wang, X., Valdes, P. J., Su, T., Zhang, Q., Zhang, L., Cai, F., Wang, H., Li, Z., Song, P., Guo, X., & Yue, Y. (2020). The early Eocene rise of the Gonjo Basin, SE Tibet: From low desert to high forest. *Earth and Planetary Science Letters*, *543*, 116312. <https://doi.org/10.1016/j.epsl.2020.116312>.

Xiong, Z., Liu, X., Ding, L., Farnsworth, A., Spicer, R. A., Xu, Q., Valdes, P., He, S., Zeng, D., Wang, C., Li, Z., Guo, X., Su, T., Zhao, C., Wang, H., & Yue, Y. (2022). The rise and demise of the Paleogene Central Tibetan Valley. *Science Advance*, *8*(6), eabj0944. <https://doi.org/eabj0944.10.1126/sciadv.abj0944>.

Xu, Q., Ding, L., Zhang, L., Yang, D., Cai, F., Lai, Q., Liu, J., & Shi, R. (2010). Stable isotopes of modern herbivore tooth enamel in the Tibetan Plateau: Implications for paleoelevation reconstructions. *Chinese Science Bulltin*, *55*(1), 45-54. <https://doi.org/10.1007/s11434-009-0543-2>.

Xu, Q., Ding, L., Zhang, L., Cai, F., Lai, Q., Yang, D., & Jing, L. (2013). Paleogene high elevations in the Qiangtang Terrane, central Tibetan Plateau. *Earth and Planetary Science Letters*, 362, 31-42. <https://doi.org/10.1016/j.epsl.2012.11.058>.

Xu, Q., Ding, L., Hetzel, R., Yue, Y., & Rades, E. F. (2015). Low elevation of the northern Lhasa terrane in the Eocene: Implications for relief development in south Tibet. *Terra Nova*, *27*(6), 458-466. <https://doi.org/10.1111/ter.12180>.

Xu, Q., Ding, L., Spicer, R. A., Liu, X., Li, S., & Wang, H. (2018). Stable isotopes reveal southward growth of the Himalayan-Tibetan Plateau since the Paleocene. *Gondwana Research*, *54*, 50-61. <https://doi.org/10.1016/j.gr.2017.10.005>.

Zhang, B., Liu, J., Chen, W., Zhu, Z., & Sun, C. (2020). Late Eocene magmatism of the eastern Qiangtang block (eastern Tibetan Plateau) and its geodynamic implications. *Journal of Asian Earth Sciences*, *195*, 104329. <https://doi.org/10.1016/j.jseaes.2020.104329>.

Zhuang, G., Brandon, M. T., Pagani, M., & Krishnan, S. (2014). Leaf wax stable isotopes from Northern Tibetan Plateau: Implications for uplift and climate since 15 Ma. *Earth and Planetary Science Letters*, *390*, 186-198. <https://doi.org/10.1016/j.epsl.2014.01.003>.

Zhuang, G., Zhang, Y. G., Hourigan, J. K., Ritts, B. D., Hren, M., Hou, M., Wu, M., & Kim, B. (2019). Microbial and Geochronologic Constraints on the Neogene Paleotopography of Northern Tibetan Plateau. *Geophysical Research Letters*, *46*(3), 1312-1319. <https://doi.org/10.1029/2018GL081505>.