Hybrid origin for syenite with mafic enclaves in the northeast North China Craton: *in situ* zircon Hf-O and apatite Sr-Nd isotopic evidence

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Whole rock geochemical composition, *in situ* apatite Sr-Nd and zircon Hf-O isotopes for syenites and their mafic enclaves were obtained to investigate the sources and processes of the Erhulai syenite in the Liaodong peninsula, North China Craton.

Field observations and zircon U-Pb ages reveal that the quartz syenites and mafic enclaves were coeval with identical emplacement ages of 129-126 Ma, slightly earlier than the porphyritic syenites (ca. 123 Ma). The quartz syenites show relatively high SiO_2, Na_2O+K_2O and low MgO contents, with evidently positive Eu anomalies. Their whole rock and *in situ* isotopic analysis show homogeneous $(^{87}Sr/^{86}Sr)_i$ ratios and $\varepsilon_{Nd}(t)$ values (–10.3 to –8.6), with variable zircon $\delta^{18}O$ values (+4.4 to +7.0 ‰) and bimodal distribution of zircon $\varepsilon_{Hf}(t)$ values. All these geochemical features can be produced by partial melting of felsic crustal materials at relatively high pressures (>30 km), with involvement of mantle-derived materials. The mafic enclaves have relatively low SiO_2 and high MgO contents, without negative Ba and Eu anomalies. They have relatively low $(^{87}Sr/^{86}Sr)_i$ ratios, with variable $\varepsilon_{Nd}(t)$ (–11.2 to –2.0) and $\varepsilon_{Hf}(t)$ (–15.8 to –5.5) values. Combined with a large proportion of zircons in mafic enclaves display mantle-derived $\delta^{18}O$ values, suggesting an enriched mantle source, with addition of crustal materials. The porphyritic syenites show medial Nd- and Hf-isotopic compositions between the quartz syenites and mafic enclaves, implying a mixing source beween two magma components mentioned above. They all have high Si characteristics, with low Ba, Sr contents and significantly negative Eu anomalies, indicating their parental magma have experienced k-feldspar, and plagioclase-dominated fractional crystallization.

In summary, a complex, multi-stage processes involving magma mixing, fractional crystallization, and wall rock assimilation was involved in genesis of the Erhulai syenites. *In situ* Sr-, Nd-, Hf- and O-isotopic analysis of accessory minerals are powerful geochemical tracers that provide unique information regarding mantle-crust interaction and magmatic processes.