DESCRIPTIVE NOTES

INTRODUCTION AND RATIONAL FOR INVESTIGATION

The area of investigation covers part of the Beishan orogenic collage and mainly comprises Late Paleozoic igneous and sedimentary rocks that were deformed during the Permian and early Triassic (Xiao et al., 2010; Mao et al., 2012; Guo et al., 2012). A contentious issue is whether the rocks formed and were deformed during closure of the last vestiges of the Paleo-Asian Ocean (Xiao et al., 2010; Mao et al., 2012) or formed in an intracontinental rift that became inverted as a result of intracontinental shortening associated with faulting (Wang et al., 2017). The area was selected in a reconnaissance study carried out in 2015 and chosen because of its excellent outcrop, structural relationships, the presence of disputed Permian oceanic rocks (Mao et al., 2012 vs Wang et al., 2017) and existing age constraints on sedimentary rocks (Cleven et al., 2018). It was mapped at 1: 25,000 scale during the summers of 2016, 2017, 2018 and 2019, but was previously mapped at 1:50,000 scale by the Gansu Bureau of Geology and Mineral Exploration and Development.

GEOLOGICAL UNITS

The rocks of the Baidunzi-heishankou area were divided into several distinct, commonly strongly tectonised lithological units, which have been assembled into six major structural panels, forming a large, predominantly north-verging imbricate stack. In structural ascendancy the tectonostratigraphic units are: (1) the Baidunzi Complex, comprising a structural collage of interleaved metasedimentary and igneous rocks; (2) the Ganquan Group, mainly comprising tectonised felsic to intermediate pyroclastic volcanic rocks; (3) the Shuangbaotang Formation, comprising tectonised volcanic-derived sedimentary rocks; (4) the Liuyuan Complex mainly comprising basalt and chert; and (5) the Cover Sequence, comprising tectonised sedimentary rocks unconformably overlying the Ganquan Group, the Shuangbaotang Formation and the Liuyuan Complex. All units are cut by late syn- to post-tectonic Late Permian and/or Triassic felsic to mafic dykes. The relationships between the Baidunzi Complex and all the other units are consistently tectonic, but the Ganquan Group and Liuyuan Complex are locally unconformably overlain by rocks of the Cover Sequence.

Baidunzi Complex

The Baidunzi Complex comprises a large volume of felsic to mafic igneous rocks and interleaved intensely deformed metasedimentary rocks. The igneous rocks invariably intruded syn-tectonically, further obscuring primary relationships.

The oldest known rocks in the Baidunzi Complex are thick-bedded orthoquartzite and minor arenitic argillaceous chlorite-muscovite schist (unit NPCBqz). The rocks form extensive ridges in the topography. They were imbricated into several thrust sheets during D3 and possibly D2 and occur near the contact between panels 2 and 3 (see below) in the central part of the area, which were stitched by ca. 281 Ma hornblende gabbro intrusions (PBgb). The youngest detrital zircon in the quartzite is ca. 1000 Ma and they are older than the ca. 295 Ma intrusive diorite (CPBdigb) and tonalite (CPBtogd) of panel 2. They may be unconformably overlain by conglomerate, arkose and feldspathic arenite of unit CPBss, although this contact is consistently highly strained.

Unit CPBsh comprises dark grey to black shale and calcareous mudstone, locally interbedded with marble CPBmb. White to pink coloured banded marble (CPBmb) is a unit that occurs throughout panel 2 and as xenoliths in diorite and tonalite gneiss in panel 1. It defines an isoclinally folded, regional-scale ghost marker in panel 2. The marble in panel 2 is older than the ca. 295 Ma diorite and granite, but younger than ca. 297 Ma detrital zircons measured in a dirty marble layer (calcareous arenite). These age constraints suggest they are potential correlatives of fossiliferous Late Carboniferous to Early Permian limestone occurring immediately west of the nearby town of Liuyuan (Guo et al., 2012 and references therein). Relationships with the quartzite of unit NPCBqz, which consistently occurs to the west or northwest of the marble, are obscured by the sheared plutonic rocks of the Baidunzi Complex. Both the quartzite and marbles are spatially closely associated and locally structurally interleaved with the immature siliciclastic rocks of unit CPBss, suggesting units NPCBqz and CPBmb were amalgamated during or before deposition of unit CPBss.

Unit CPBss comprises immature arkose, feldspathic arenite, conglomerate and semi-pelitic rocks. The latter was metamorphosed into biotite-muscovite schist. They occur adjacent to both unit NPCBqz and CPBmb with high-strain contacts. However, their widespread distribution throughout panel 2 suggest they represent an unconformable cover sequence to both. They are older than the ca. 295 Ma diorite, but younger than ca 297 Ma detrital zircons.

Units CPBdigb, CPBtogd, PBgrgd, PBgb and PBtr generally comprise sheared sheets of fine to coarse grained hornblende quartz diorite, tonalite, granite, gabbro and trondhjemite, which intruded syn-tectonically into units NPCBqz-CPBss. Diorite, tonalite and granite form the oldest components with intrusion starting at ca. 295 Ma and continuing intermittently until ca. 281 Ma in panel 2. Gneissic diorite and tonalite in panel 1 have ages between ca. 326 and ca. 336 Ma. The youngest intrusive rocks are granite dykes, which yielded an age of ca. 255 Ma in panel 1. Diorite and tonalite are locally transformed into garnet and/or hornblende-bearing gneisses (CPBdigb-gn & CPBtogd-gn) in panel 1 and locally also in panel 2. Garnet occurs in tonalite and trondhjemite in panel 2, but is relatively rare.

Unit PBsscg comprises dark grey, green or red epiclastic sandstone, siltstone and conglomerate. The conglomerate contains granite and felsic volcanic clasts and occurs only in panels 3 and 5. Sandstone contains medium to coarse fragments of white rhyolite. Locally it contains beds of volcanically derived fragmental rocks, white to black layered cherty ash and minor crystal tuff. This unit might be lithologically correlated to unit PSss of Shuangbaotang formation, but detrital zircons yielded an older age of ca. 293 Ma than tuff beds of unit PSss, which yielded a U-Pb zircon age of ca. 281 Ma, whereas both unit was intruded by numerous ca. 281 Ma gabbro sills (PBgb), suggesting the rocks were deposited rapidly coeval with bimodal magmatism. Volcanic clasts and fragments are possibly derived from the 297-292 Ma Ganquan Group volcanic rocks of panels 3 and 4. If correct, the Ganquan group and Baidunzi complex were proximal by ca. 280 Ma.

Ganquan Group

The Ganquan Group mainly comprises rhyolite to rhyodacite crystal and lithic tuff (units PGtfp and PGtfl, respectively) and an unconformable cover of red sedimentary and interlayered white to light green tuffaceous rocks (PSrb and PSrbtf). Yellow, light green, red or white quartz- and/or feldspar-phyric crystal tuff is the most voluminous unit (PGtfp). The rhyolite tuff of unit PGtfp was intruded by several ca. 285 Ma red biotite granite bodies (PGgr), which probably represent subvolcanic intrusions. Unit PGtfp locally includes volcaniclastic sedimentary rocks characterised by rounded phenoclasts of quartz and may include lava flows and/or subvolcanic porphyritic intrusions. Large-scale mylonitization into phyllonites generally obscured most primary features. Unit PGtfl predominantly comprises light green to yellow lithic tuff, but also include a small volume of green andesite and/or basalt and minor interlayered quartz and/or feldspar phyric tuff of unit PGtfp. Tuff of units PGtfp and PGtfl yielded U-Pb zircon ages between 297 and 292 Ma, but relative age relationships between these two units are undetermined, due to the high strain accommodated by the Ganquan Group rocks, which transformed most rocks into greenschist facies phyllonites. The silicic volcanic rocks have calc-alkaline compositions, but geochemical/isotopical studies revealed there is little or no zircon inheritance, suggesting the volcanic rocks might be juvenile and represent an intra-oceanic arc. Hence, the Ganquan Group is exotic with respect to coeval magmatic rocks in the adjacent Baidunzi Complex, consistent with the observation that plutonic rocks of the Baidunzi Complex have not intruded into the Ganquan Group. The volcanic rocks are interpreted to be unconformably overlain by red to purple, occasionally light green shale, gritty sandstone and conglomerate (PGrb), which generally show less strain than the underlying rocks. Conglomerate contains volcanic clasts of underlying tuff of units PGtfp and PGtfl, and vein quartz. Rocks of PGrb are interlayered with thin white felsic ash beds and green andesite tuff (PGrbtff). Both types of tuff yielded identical U-Pb zircon ages of ca. 282 Ma.

Shuangbaotang Group

The volcanic rocks of the Ganquan Group in panel 4 are interpreted to be unconformably overlain by red to purple, occasionally light green shale, gritty sandstone, and conglomerate (PSrb) of Shuangbaotang Formation, which generally show less strain than the underlying rocks. Conglomerate contains volcanic clasts of underlying tuff of units PGtfp and PGtfl, and vein quartz. Rocks of PSrb are interlayered with thin white felsic ash beds and green andesite tuff (PSrbtf). Both types of tuff yielded identical U-Pb zircon ages of ca. 282 Ma.

Unit PSss comprises light grey, brown or black tuffaceous or volcaniclastic shale, sandstone, and conglomerate. Shale and siltstone are micaceous and metamorphosed to slate or phyllite. Sandstone contains fine to medium-sized white volcanic fragments and is locally garnet-bearing. Conglomerate contains fragments of rocks red granite, white felsic volcanic clasts and calcareous lithic clasts, which may come from Baidunzi Complex and Ganquan Group. Rocks of this unit were intruded by gabbro PBgb, and locally contains beds of grey to black layered cherty ash and only occur in Panel 5. Crystal tuff beds of this unit yielded a U-Pb zircon age of ca. 275 to 283 Ma, which differs this unit from unit PBsscg. In panel 5, unit PSss structurally overlies nappes of unit PGtfp. The metamorphism of this hanging wall may suggest an earlier burying event occurred before the thrust.

Liuyuan Complex

The Liuyuan Complex mainly comprises green to bluish green, locally vesicular pillow and massive basalt (unit PLbs) intruded by minor diabase and rare grey plagioclase-rich trondhjemite. The basalt is interlayered with thin beds of varicoloured chert (unit PLch). A thin layer of red hematite-rich metalliferous rock (red ochre) was observed at one location. The rock association of basalt, chert and trondhjemite indicates the Liuyuan Complex comprises oceanic rocks. The basalt is overlain by grey to light green massive dacite or siliceous andesite flows and/or sills (unit PLda), which are locally structurally interleaved and/or interbedded with fine conglomerate (containing chert and basalt clasts) of the Shuangbaotang Group (unit PTscgm); the conglomerate marks the presence of an unconformity between the Liuyuan Complex and the Shuanbaotang Group. The dacite and/or andesite of PLda yielded U-Pb zircon ages between ca. 276 Ma and 267 Ma, whereas a trondhjemite of the Liuyuan Complex collected to the north of the study area, yielded a U-Pb zircon age of ca. 285 Ma. The rocks of the Liuyuan Complex were metamorphosed to greenschist facies conditions.

Cover Sequence

The Cover Sequence comprises sedimentary rocks that were metamorphosed to low greenschist or sub-greenschist facies conditions and its youngest unit (PTscgm) unconformably overlies rocks of the Ganquan Group, Liuyuan Complex, Shuangbaotang Group and the older units of Cover Sequence. Unit PTscgm is thus younger than 281 Ma, consistent with its youngest detrital zircons of ca. 280 Ma. Conglomerate (PTscgf and PTscgm) contain pebbles and boulders of sedimentary and igneous rocks derived from the Baidunzi Complex, the Ganquan Group and the Liuyuan Complex, whereas the polyphase deformation history of the Cover Sequence is partly shared with the older units. It lacks the oldest structures and fabrics (D1) observed in the Baidunzi Complex. Hence, the Cover Sequence was deposited syn-tectonically during uplift and exhumation and represents an overstep sequence dissected by two internal unconformities. The basin of the Cover Sequence is interpreted as a foredeep.

The Cover Sequence units are described in stratigraphic order from old to young, based on internal unconformities and younging indicators such as graded bedding, scours and cross bedding. The oldest unit (Unit PTssh) is represented by dark grey to black shale interlayered with micaceous sandstone and rare conglomerate. It occurs adjacent to both sedimentary rocks of CPBss and PBsscg, and is locally structurally interleaved with limestone (PTssh-lm). Neither the shale nor intercalated limestone were intruded by the plutonic rocks of the Baidunzi Complex. Unit PTssh is thus probably younger than the youngest ca. 281 Ma mafic intrusions of the Baidunzi Complex. Its youngest detrital zircons are ca. 293 Ma. Unit PTssh was intruded by a Lower Triassic quartz-phyric rhyolite porphyry dyke (Tdk), which yielded a U-Pb zircon age of ca. 241 Ma.

Unit PTssh is unconformably overlain by a polymict conglomerate interbedded with light green, quartz-rich, commonly thick-bedded sandstone (unit PTscgf). The conglomerate contains abundant pebbles and boulders of metamorphosed and deformed igneous and sedimentary rocks of the Baidunzi Complex and is thus younger than ca. 281 Ma. Unit PTscgf is gradually overlain by light green, quartz-rich, commonly thick, locally cross-bedded sandstone (PTsss), which is the same sandstone as in unit PTscgf, but without conglomerate. Unit PTsss is conformably overlain by light green to brownish siltstone interbedded with thin-bedded, graded sandstone (PTssi). Unit PTssi is unconformably overlain by dark green conglomerate typically interleaved with sandstone and green to purplish siltstone (unit PTscgm). It contains clasts of basalt (PLbs), chert (PLch) and underlying rocks of units PTscgf, PTsss and PTssi. It also unconformably overlies the basalts (PLbs) of the Liuyuan Complex and rocks of the Ganquan Group. Age



K46F036043	K46F036044	K46F036045	K46F036046	K46F036047
K46F037043	K46F037044	K46F037045	K46F037046	K46F037047
K46F038043	K46F038044	K46F038045	K46F038046	K46F038047
K46F039043	K46F039044	K46F039045	K46F039046	K46F039047

Geology by:
Cees R. van Staal, Shoufa Lin, Tong Hong, Wenhua Ji (for Baidunzi Area East)
Tong Hong, Cees R. van Staal, Shoufa Lin, Wenhua Ji (for Baidunzi Area West)
Tong Hong, Cees R. van Staal, Shoufa Lin, Wenhua Ji (for Heishankou Area East)
Cartography by:
Étienne Girard, Tong Hong, Shuping Wang, Bo Yang

STRUCTURE

The structural history of the area is complex. It involved at least three generations of ductile and locally brittle structures in the Baidunzi Complex and Ganquan Group. The generations of structures were grouped into D1, D2 and D3 on basis of kinematic analysis, overprinting relationships, unconformities, and syn-tectonic sedimentation. The oldest phase of structures (D1) is missing in the Cover Sequence and possibly also in the Liuyuan complex, suggesting it took place before deposition of the former. Ductile structures comprise folds, thrust-related shear zones and dextral and sinistral oblique normal and reverse transcurrent shear zones and faults. D3-related thrusting was characterized by north-directed tectonic transport along shallowly to moderately south-dipping shear zones characterized by paper-thin phyllonites and mylonites. This phase of shearing was most significant for the present distribution of the rocks. D3 thrusts assembled the various rock units, with the exception of the Liuyuan Complex, into four major, north-translated structural panels, each panel characterized by distinct geological units and/or tectono-stratigraphy. The Liuyuan Complex in panel 6 and the mixture of rocks of the Ganquan Group and Baidunzi Complex in panel 5 are situated in south-directed, folded thrust panels, which are inferred to have formed during D2. Panels 5 (structural mixture of the Ganquan Group and the Baidunzi Complex) and 6 (Liuyuan Complex) have been overthrust by panel 4 (Ganquan Group) during D3 thrusting, truncating the older D2 structures. Panel 6 (Liuyuan Complex) was emplaced during D2 above the Cover Sequence. Its base is characterized by a south-directed, northwards-dipping brittle-ductile thrust, marked by phyllonite, fault gouge and abundant, thick quartz veins, which extend for considerable distances along strike.

D1 structures have only been observed in rocks of the Baidunzi Complex and Ganquan Group. They comprise a gneissic layering in panel 1 and panel 2 (S1), compositional layering-parallel foliation (S1), isoclinal intrafolial folds (F1) in compositional layering and quartz veins. It is possible that the various S1 foliations in part formed during different events, which cannot be separated with the present database. They are all overprinted by D2.

D2 structures comprise isoclinal to tight folds (F2), a crenulation cleavage (S2), which is generally only preserved in the hinges and large ductile-brittle shear zones, which were refolded by F3. The main foliation along the limbs of the F2 folds is generally a composite foliation of S1 and S2. South-directed D2 thrusts folded by F3 occur in the Liuyuan Complex and the Cover Sequence and probably caused structurally interleaving of the Ganquan Group and Baidunzi Complex in panels 3 and 5.

D3 comprises large, steeply inclined or upright east-west trending, shallowly to moderately east or west plunging, open to tight folds (F3) and thrust-related shear zones. D3 shear zones locally truncate E-W trending F3, but are also folded by them, suggesting D3 is a progressive event involving coeval thrusting-related shearing and folding.

STRUCTURAL PANELS

The structural panels divide the rocks into distinct thrust-bounded tectonostratigraphic assemblages. Rocks of the Baidunzi Complex occur in panels 1, 2, and 3. In panels 3 and 5, rocks of the Baidunzi Complex are structurally interleaved with volcanic rocks of the Ganquan Group following isoclinal F2 folding of the intervening shear zones. The panels are described below in ascending structural order.

Panel 1 mainly comprises diorite, tonalite, trondhjemite and granite bodies of the Baidunzi Complex. An old phase of diorite and tonalite (ca. 336-326 Ma) was transformed into garnet-hornblende bearing orthogneiss, locally containing xenoliths of marble. The orthogneiss is cut by younger phases of tonalite (ca. 271 Ma), trondhjemite and granite.

Panel 2 comprises a mixture of pre-295 Ma transposed metasedimentary rocks (NPCBqz, CPBsh, CPBmb, and CPBss) injected by numerous syntectonic sheets of ca. 295-280 Ma diorite, tonalite, trondhjemite and granite of the Baiduinzi Complex. The granitoid sheets are most abundant in the southern part of panel 2.

Panel 3 comprises structurally interleaved meta-felsic volcanic rocks of the Ganquan Group and sedimentary and igneous rocks of the Baidunzi Complex. Ca. 281 Ma volcaniclastic sediments and tuff (PBsscg) and hornblende gabbro (PBgb) are tightly to isoclinally folded (F2) with the Ganquan Group, yet the gabbro has not intruded the volcanic rocks, indicating that D2 mainly took place after ca. 281 Ma.

Panel 4 comprises highly deformed and mylonitised volcanic rocks and subvolcanic intrusions of the Ganquan Group (ca.297-283 Ma). The volcanic rocks were nowhere intruded by igneous rocks of the Baidunzi complex, neither interlayered with Baidunzi complex sediments, suggesting these two units represent different tectonic settings and provenances, which were tectonically juxtaposed after ca. 281 Ma.

The tectono-stratigraphy of Panel 5 is similar to that of panel 3 with volcanic rocks of the Ganquan Group structurally overlain by sedimentary rocks of Shuangbaotang Formation PSss and gabbro PBgb of Baidunzi Complex. Both units and intervening thrusts are folded into a moderately east-plunging open F3 antiform, whose southern limb is truncated by the basal D3 thrust of panel 4. The rocks of the Shuangbaotang Formation are structurally overlain by unit PTssh of the Cover Sequence and unconformably overlain by rocks of unit PTscgm. Unit PBsscg overlies the older volcanic rocks of the Ganquan Group in the core of the F3 fold, yet its entrained hornblende gabbro (PBgb) sills did not intrude into the underlying, older volcanic rocks (PGtfp), indicating the contact is structural. The geometry suggests the Baidunzi Complex and Ganquan Group rocks and intervening thrust in this panel occupy the inverted limb of a recumbent, south-verging F2 fold.

Panel 6 comprises igneous and sedimentary rocks of the Liuyuan Complex and the unconformably overlying conglomerate and siltstone of the Cover Sequence (PTscgm), which together were thrust southwards over the older units of the Cover Sequence that form part of panel 5. The structural core of panel 6 occurs in shallowly, doubly plunging F3 antiforms, which probably also fold the underlying basal ductile-brittle thrust. The basal D2 thrust is marked by phyllonite, fault gouge and thick, laterally extensive, locally brecciated quartz veins. D2 is thus younger than ca. 281 Ma.

METAMORPHISM

Metamorphism varies throughout the Baidunzi area from amphibolite in the southernmost parts (panel 1) to greenschist and sub-greenschist facies conditions in the north. Amphibolite facies rocks only occur in rocks of the Baidunzi Complex. Amphibolite facies assemblages are represented by biotite, hornblende and/or garnet in mafic to intermediate rocks in panels 1 and 2. Greenschist facies rocks, represented by combinations of actinolite, epidote, phengite, biotite, chlorite, albite, microcline and minor garnet, occur in rocks of the Baidunzi Complex, the Ganquan Group and the Liuyuan Complex situated in panels 2, 3, 4, 5 and 6. Parts of the Cover Sequence rocks (PTscgm) are dominated by chlorite and may be metamorphosed to sub-greenschist facies conditions.

AGE OF DEFORMATION AND METAMORPHISM

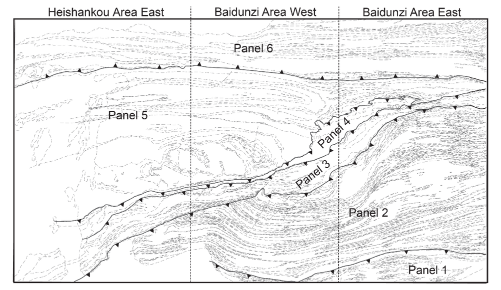
The D1 deformation and associated amphibolite to greenschist facies metamorphism is at least as old as ca. 296 Ma, the age constraints provided by U-Pb zircon ages for the syn-tectonic diorite, tonalite and granite intrusions. Some of the gneisses in panel 1 may be older, but if so, are younger than ca. 336 Ma. D2 shearing and associated folding (F2) started after ca. 281 Ma (age of hornblende gabbro of unit PBgb, but before intrusion of the ca. 241 Ma rhyolite porphyries. D2 fabrics are well developed in the oldest units of the Cover Sequence, but weakly developed or absent in unit PTscgm, suggesting D2 overlapped with deposition of part of this unit. D3 folding and thrusting is present in all units and hence younger than deposition of the Cover Sequence. A weak S3 cleavage is locally present in the ca. 241 Ma rhyolite porphyries, which are approximately parallel to the axial plane of large F3 folds, suggesting D3 mainly took place during the early Triassic.

TECTONIC SETTING

The Baidunzi Complex, Ganquan Group and Liuyuan Complex represent three different, unrelated Late Carboniferous to Early Permian tectonic settings. The Liuyuan Complex represents a vestige of Early Permian (ca. 285 Ma) oceanic crust, whereas the Ganquan Group (ca. 295 Ma) probably represents part of a juvenile volcanic arc. Panel 2 of the Baidunzi complex represents part of a Late Carboniferous passive margin injected by syn-tectonic Early Permian magmatic rocks, whereas Panel 1 preserved the remnants of a Late Carboniferous tectono-magmatic event overprinted by Permian magmatism. All three units were juxtaposed and amalgamated during D1-D3 deformation that involved both south- and north-directed tectonic transport, related to closure of a Permian oceanic seaway and arc-(micro)continent collision.

Geochronology

Sample ID	Latitude	Longitude	Lithology	Age (Ma)	Method	Map Code
V301	40.954365	95.547099	felsic porphyry dyke	241 ± 2	LA-ICP-MS	Tdk
V1340	40.9645632	95.7080417	dacite	267 ± 4	SHRIMP	PLda
V53	40.96290993	95.60949845	dacite	276 ± 2	LA-ICP-MS	PLda
V233	40.9546851	95.6928173	andesitic tuff	282 ± 4	SHRIMP	PSrb
V176	40.95063333	95.6594944	andesitic tuff	283 ± 2	SHRIMP	PSrbtf
S35A	40.945097	95.659334	felsic lithic tuff	292 ± 2	LA-ICP-MS	PGtfl
H3025	40.900165	95.47796	rhyolitic phyric volcanics	283 ± 2	SHRIMP	PGtfp
H3090A	40.917667	95.513647	rhyolitic tuff	292 ± 2	SHRIMP	PGtfp
S85	40.897134	95.530468	rhyolitic tuff	297 ± 3	SHRIMP	PGtfp
V1082	40.89894014	95.5656613	granite	285 ± 2	SHRIMP	PGgr
V1106	40.890156	95.500638	granite	286 ± 3	SHRIMP	PGgr
V163	40.942383	95.692156	gabbro	281 ± 2	SHRIMP	PBgb
H3345	40.90218	95.468503	gabbro	286 ± 6	SHRIMP	PBgb
V1371	40.842438	95.688218	granite dyke	255 ± 2	SHRIMP	PBgrgd
V370	40.8871932	95.6774826	granodiorite	294 ± 1	LA-ICP-MS	PBgrgd
H3009	40.924383	95.498943	felsic tuff	281 ± 2	SHRIMP	PSss
V1096	40.88392097	95.62462602	tonalite dyke	281 ± 3	SHRIMP	CPBtogd
H3090B	40.858653	95.621891	tonalite dyke	287 ± 3	SHRIMP	CPBtogd
S5141A	40.83270186	95.58671772	tonalite dyke	271 ± 3	SHRIMP	CPBtogd-gn
S5042	40.84389979	95.64359596	tonalitic orthogneiss	324 ± 8	SHRIMP	CPBtogd-gn
V1109	40.843991	95.603838	tonalitic gneiss	461 ± 9	SHRIMP	CPBtogd-gn
S5145A	40.85136576	95.59033544	diorite	284 ± 3	SHRIMP	CPBdigb
V266	40.8983118	95.6363837	diorite	295 ± 4	SHRIMP	CPBdigb
V1313C	40.850629	95.681796	dioritic orthogneiss	336 ± 3	SHRIMP	CPBdigb-gn
V162	40.941192	95.692281	conglomerate	< ca 293	LA-ICP-MS	CPBss
S22A	40.92775	95.6576	conglomerate	< ca 440	LA-ICP-MS	CPBss
V361	40.872022	95.639993	marble	< ca 295	LA-ICP-MS	CPBmb
H18	40.909445	95.640935	quartzite	< ca 1000	LA-ICP-MS	nPCBqz



ACKNOWLEDGMENTS

The mapping was conducted as a part of China Geological Survey projects DD20160009 and DD20190004, through a collaboration of China Geological Survey (Xi'an Centre, CGS and Institute of Geology, CAGS), the University of Waterloo and the Geological Survey of Canada. We thank Changcheng Li, Wenming Li, Kai Wang, Meiling Wu, Jiming Sun, Bo Yang and Jin Zhang for their contributions to mapping and/or logistical support, and Jean Bedard, Zhenyu He, John Waldron, Tao Wang, Chris Yakymchuk, Jianguo Yang and Jian Zhang for discussions in and out of the field. We are grateful for the field assistance by Xiqin Chen, Lamei Feng, Lingchao He, Jiangyu Li, Xun Li, Tianyu Lu, Peng Song, Yueting Song, Chaoyang Wang, Lijun Wang, and Yanfei Xia.

REFERENCES

Cleven, N.R., Lin, S., Xiao, W., Davis, D.W., & Davis, B. (2018). Successive arc accretion in the southern Central Asian orogenic belt, NW China: Evidence from two Paleozoic arcs with offset magmatic periods. Geological Society of America Bulletin, 130, 537-557.

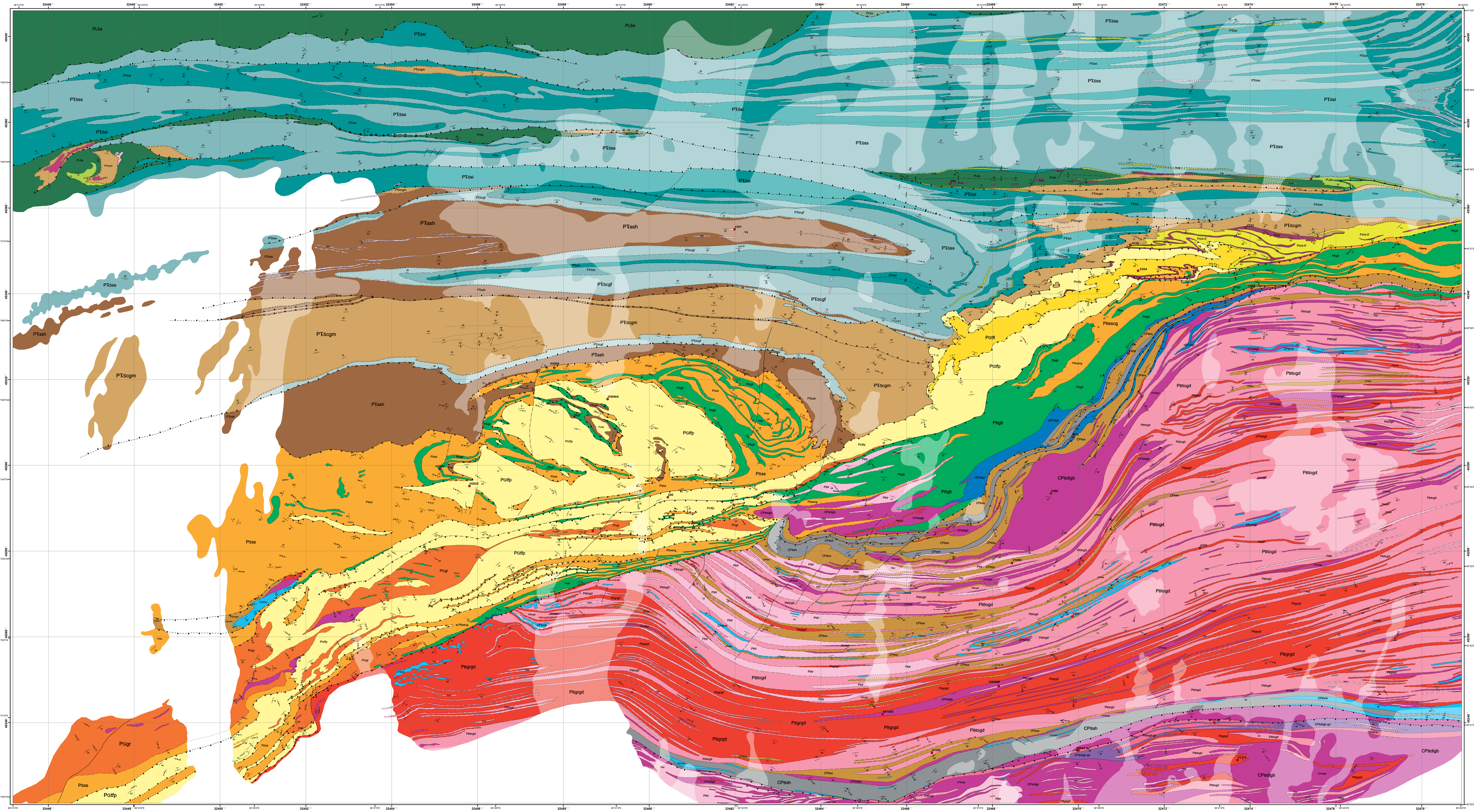
Guo, Q., Xiao, W., Windley, B.F., Mao, Q., Han, C., Qu, J., ... & Yong, Y. (2012). Provenance and tectonic settings of Permian turbidites from the Beishan Mountains, NW China: implications for the Late Paleozoic accretionary tectonics of the southern Altaids. Journal of Asian Earth Sciences, 49, 54-68.

Mao, Q., Xiao, W., Windley, B.F., Han, C., Qu, J., Ao, S., ... & Guo, Q. (2012). The Liuyuan complex in the Beishan, NW China: a Carboniferous–Permian ophiolitic fore-arc sliver in the southern Altaids. Geological Magazine, 149, 483-506.

Wang, Y., Luo, Z., Santosh, M., Wang, S., & Wang, N. (2017). The Liuyuan Volcanic Belt in NW China revisited: evidence for Permian rifting associated with the assembly of continental blocks in the Central Asian Orogenic Belt. Geological Magazine, 154, 265-285

Xiao, W., Mao, Q., Windley, B.F., Han, C., Qu, J., Zhang, J., & Shan, Y. (2010). Paleozoic multiple accretionary and collisional processes of the Beishan orogenic collage. American Journal of Science, 310, 1553-1594.

dos Santos, G., Bédard, J., Lin, S., & van Staal, C. (2019). The Liuyuan Complex in the Beishan Orogen, NW China: an ophiolite at the southern edge of the Central Asia Orogenic Belt. GAC-MAC-IAH 2019, Québec, Canada.



Recommended citation:
van Staal, C.R., Hong, T., Lin, S., Ji, W.H, 2021. Bedrock Geological Map of the Baidunzi-Heishankou Area, Guazhou, Gansu, China, scale 1:25,000: China Geological Survey, DOI: 10.35080/data.C.2021.P01.

Map projection: UCGCS2000 3 Degree GK Zone 32

LEGEND

TRIASSIC

Tdk — **Dikes and Sills:** narrow dikes and sills of quartz-phyric rhyolite porphyry, granite, rare gabbro and tonalite; weakly foliated to unfoliated. A rhyolite porphyry dike yielded a U-Pb zircon age of ca. 241 Ma.

PERMIAN TO TRIASSIC

COVER SEQUENCE

The Cover Sequence comprises sedimentary rocks that were dissected by internal unconformities and complexly folded and imbricated at low greenschist or sub-greenschist facies conditions. The following rock units of this sequence are described in stratigraphic order.

PTscgm — **Conglomerate,** characterized by abundant mafic volcanic clasts (basalt from unit PLbs). Also include clasts of chert (PLch) and underlying rocks of units PTscgf, PTsss and PTssi. Interlayered with sandstone and green to purplish siltstone. Unconformably overlies Liuyuan Complex and older units of Shuangbaotang Group.

Unconformity

PTssi — **Siltstone,** interbedded with thin-bedded, graded sandstone, light green, light greyish blue, or light purplish blue in color.

PTsss — **Sandstone,** light green or light brown in color, quartz-rich, commonly thick, locally cross-bedded; same as sandstone in unit PTssh, but without conglomerate.

PTscgf — **Conglomerate,** with abundant 'felsic' clasts of granitoid, vein quartz and quartzite, and rare clasts of gabbro, all from the Baidunzi Complex; interbedded with light green quartz-rich, commonly thick-bedded sandstone. Unit unconformably overlies PTssh.

Unconformity

PTssh / lm — **Shale,** interbedded with sandstone, grit and limestone: Dark grey to black shale, micaceous sandstone, rare gritty conglomerate and minor limestone (PTssh-lm). Occurs adjacent to both sedimentary rocks of PSss and PGtfp, but is not intruded by the plutonic units of the Baidunzi Complex. Instead, this unit was intruded by a Lower Triassic quartz-phyric rhyolite (Tdk) where it unconformably underlies unit PTscgf. Hence, this unit is Late Permian to Early Triassic, possibly representing part of an overstep sequence.

PERMIAN

LIUYUAN COMPLEX

The Liuyuan Complex mainly comprises green to bluish green, locally vesicular pillow basalt, which is locally interlayered with thin beds of varicoloured chert. Also include sheeted dykes, subordinate gabbro, trondhjemite, and associated turbiditic and carbonate sedimentary rocks (dos Santos et al., 2019). Rocks of Liuyuan Complex in the mapping area were metamorphosed to greenschist facies conditions and are in tectonic contact with structurally underlying units.

PLda — **Dacite:** grey to light green massive dacite or locally siliceous andesite flows and/or sills. Overlies basalt and chert of units PLbs and PLch. It yielded a U-Pb zircon age of ca. 267 and 276 Ma and stratigraphic relationships with underlying rocks and rocks of the cover sequence are presently not well defined.

PLch — **Chert,** varicolored, occurring as thin beds interlayered with pillow basalt.

PLbs — **Pillow and massive basalt,** green to bluish green, locally vesicular; locally intruded by grey plagioclase-rich trondhjemite and diabase. Rocks are older than ca. 276 Ma.

SHUANGBAOTANG GROUP

PSss — **Sandstone,** commonly tuffaceous or volcaniclastic, interlayered with shale, siltstone, and conglomerate; light to dark grey, brown, greenish grey or black in color. Shale and siltstone are micaceous and metamorphosed to slate or phyllite. Sandstone contains fine to medium-sized white volcanic fragments. Conglomerate contains fragments of red granite, white felsic volcanic clasts, and white calcareous lithic clasts. Conglomerate contains locally beds of grey to black layered cherty ash. Includes minor crystal tuff beds. Tuff beds yielded a U-Pb zircon age of ca. 275 to 283 Ma, intruded by gabbro (PBgb).

PGrb / tf — **Red beds:** mainly red to purple, occasionally green shale, gritty sandstone and conglomerate (PGrb). Conglomerate contains volcanic clasts of underlying felsic tuff and vein quartz. Rocks are interlayered with thin white felsic ash beds, green andesite tuff and volcanogenic sediments (PGrbtf). Both types of tuff yielded U-Pb zircon ages of ca. 282 Ma. Unit probably marks an unconformity and shares lithological similarities with coeval unit PBsscg.

GANQUAN GROUP

The Ganquan Group mainly comprises Upper Carboniferous to Early Permian yellow, red to brown thick bedded rhyolite with minor green andesite, felsic tuff, and interbedded siltstone/shale, which are strongly deformed and metamorphosed to greenschist facies conditions. Contacts between the Ganquan Group and adjacent units are generally tectonic but is unconformably overlain by the Shuangbaotang Group.

PGtfl — **Lithic tuff,** light green to yellow. Lithic clasts predominate. Includes rare andesite or basalt and minor interlayered quartz and/or feldspar phyric tuff of unit PGtfp. Tuff of unit PGtfl yielded U-Pb zircon ages of 292 Ma.

PGtfp / PGgr — **Phyric tuff:** Predominantly quartz and/or feldspar-phyric tuff, yellow, light green, red or white in color. Locally include lava flows and/or subvolcanic porphyritic intrusions. May includes extensive sheets of ca. 285 biotite granite (PGgr), which probably represent sub-volcanic intrusions. Locally includes some volcaniclastic sedimentary rocks. Volcanogenic sandstone typically contains rounded phenocrysts of quartz. Includes some light green lithic tuff of unit PGtfl. Intense deformation generally transformed the rocks into tectonites and micaceous mylonites (phyllites). Tuff of unit PGtfp yielded U-Pb zircon ages between 292 and 297 Ma.

NEOPROTEROZOIC TO PERMIAN

BAIDUNZI COMPLEX

The Baidunzi Complex comprises a tectonic mixture of heterogeneously sheared and transposed meta-plutonic and metasedimentary rocks, which are imbricated into 3 structural panels. Hence, original stratigraphic relationships are obscured and contacts with other units are generally tectonic. All rocks are metamorphosed from greenschist to amphibolite facies and strongly to weakly foliated, but herein mostly described as protoliths. Units are presented in approximate geochronological order from oldest to youngest based on field relationships, rare younging indicators and U-Pb zircon geochronology. Most igneous rocks intruded syn-kinematically with respect to early deformation and are commonly smeared-out into lenticular sheets.

PBtr — **Leucogranite to tonalite,** plagioclase-phyric, mainly white, hornblende or biotite and/or muscovite-bearing, locally comprising trondhjemite. Plagioclase phenocrysts typically have a blocky appearance. Intrudes all other igneous units and generally forms small intrusive sills that are subparallel to the contacts of units CPBdigb to PBsscg.

PBgb — **Hornblende gabbro,** green in color. It has U-Pb zircon ages of between ca. 281 and 286 Ma. Intrudes diorite and tonalite in Baidunzi panel 3 and stitches the contact between panels 2 and 3. Deformation is heterogeneous and mainly concentrated near contacts.

PBgrgd — **Granite to granodiorite:** fine to coarse grained red or pink to white biotite-muscovite granite to biotite granodiorite. Includes aplite and pegmatite phases. Granite yielded U-Pb zircon ages between ca. 290 to 294 Ma in panel 2 and ca. 255 to 274 Ma in panel 1. Intruded ca. 290 Ma diorite of unit CPBdigb and ca. 290 Ma tonalite of unit PBtogd. Commonly spatially closely associated with sedimentary rocks of units CPBmb and CPBss, which locally occur as narrow screens between the granite sheets and with which it locally forms large bodies of injection migmatite. Also includes small intrusive sheets of trondhjemite and lenticular screens of older diorite and tonalite.

PBsscg — **Sandstone to conglomerate,** commonly volcaniclastic, interlayered with siltstone; dark grey, green, or red in color. Conglomerate contains granite and felsic volcanic clasts. Sandstone contains medium to coarse fragments of white rhyolite. Include minor crystal tuff beds. Tuff beds yielded a U-Pb zircon age of ca. 291 Ma. Both conglomerate and volcaniclastic sandstone yielded maximum depositional age ca. 292 Ma. Intruded by gabbro (PBgb) and trondhjemite (PBtr).

CPBtogd / gn — **Tonalite to granodiorite,** fine to coarse-grained, white to grey in color, biotite and/or hornblende-bearing. Locally grades into quartz diorite and contains small intrusive sheets of granite and trondhjemite. Intruded ca. 290 Ma diorite of unit CPBdigb, but elsewhere was itself intruded by ca. 294 Ma granite of unit PBgrgd. Tonalite probably intruded during a considerable time span, since U-Pb zircon analysis suggests emplacement of tonalite dykes at ca.290 Ma and ca. 281 Ma. A gneissic tonalite (PBtogd-gn) associated with gneissic diorite in panel 1 has a U-Pb zircon age of ca. 326 Ma, whereas a late tonalite to trondhjemite phase has an age of ca. 271 Ma in this panel. Where thin granite sheets are abundant, it locally transformed the rocks into highly tectonised migmatite in Panel 2. Commonly contains narrow screens of sandstone and wacke of CPBss and xenoliths of marble unit CPBmb.

CPBdigb / gn — **Hornblende diorite to gabbro,** fine to coarse grained, locally pegmatitic. Commonly contains small amounts of quartz and is spatially closely associated with intrusive, in part coeval tonalite (PBtogd), with which it is commonly interleaved on outcrop scale, giving the rocks a banded appearance. Also includes small intrusive sheets of granite and trondhjemite. Diorite yielded U-Pb zircon crystallization ages ca. 290 Ma, and yielded ages between 336 and 323 Ma in panel 1. Locally transformed into garnet and/or hornblende-bearing gneiss (CPBdigb-gn) in panel 1, and the diorite gneiss yielded U-Pb zircon rim ages at ca. 272Ma. Garnet also occurs in panel 2 but is relatively rare. Contains xenoliths of marble of unit CPBmb and screens of sandstone of unit CPBss.

SHIBANSHAN FORMATION

The Shibanshan formation is dominated by dark grey to black phyllite, white to grey thick-bedded marble, and coarser clastic metasedimentary rocks which were commonly metamorphosed to phyllite.

CPBss — **Sandstone,** commonly feldspathic, locally grades into conglomerate and/or arkose, thin to medium bedded, brown, grey or pink in color. Rocks of this unit are commonly spatially associated with marble of unit CPBmb, with which they are locally interleaved structurally. Intruded by granitoids of units PBtr, PBgrgd, PBtogd and CPBdigb. The sandstone yielded maximum depositional age at ca. 304 Ma.

CPBmb — **Marble,** white to pink in colour, banded, locally interlayered with thin-bedded calcareous arenite and siltstone. Unit is discontinuous and generally occurs as narrow lenticular screens between the plutonic members of the Baidunzi Complex. It defines a regional-scale ghost marker. Rocks were deposited between 330 and 295 Ma. Potentially correlated with fossiliferous Carboniferous to Early Permian limestone occurring west of the town of Liuyuan.

CPBsh — **Sandstone,** interbedded with mudstone and limestone: predominantly dark grey to black shale and calcareous mudstone, locally metamorphosed to slate or phyllite, and contains minor limestone (CPBmb). Occurs adjacent to both sedimentary rocks of CPBmb and CPBss, but most depositional contacts are obscured due to strong shearing and folding. Rocks of this unit locally young towards the limestone (CPBmb). Commonly found Intruded by leucogranite of unit PBtr and diorite of unit CPBdigb. The maximum depositional age yielded from detrital zircon U-Pb analysis is ca. 306 Ma.

THRUST

nPCBqz — **Quartzite and arenite:** white, light green or pink orthoquartzite and minor Al-rich arenite. Massive to thickly bedded. Relationships with other sedimentary units are obscured by zones of mylonite and quartz veining. Intruded by diorite and tonalite of units CPBdigb and CPBtogd, hence they are older than 295 Ma. Youngest detrital zircon is ca. 1000 Ma.

Shaded areas are areas of no outcrop, and extended areas of no outcrop are shown in white.

Lithological contact (defined or approximate, inferred, concealed)
Unconformity (defined or approximate, inferred, concealed)
Fault: thrust (defined or approximate, inferred, concealed)
Fault: general (defined or approximate, inferred, concealed)
Fold axial trace, approximate (synform, antiform)
Bedding (top unknown, known, overturned)
Fold axial plane (generations undifferentiated)
Fold hinge (generations undifferentiated)
Foliation (S1 general, S1 gneissosity, S2, S3)
Lineation (L1, L2, L3, striation)
Shear sense (dextral, sinistral)
Geochronology sample site and number

BEDROCK GEOLOGY

Baidunzi-Heishankou Area

Gansu, China

K46F037044, K46F037045, K46F037046, K46F038044, K46F038045 and K46F038046, and parts of K46F037043 and K46F038043

1:25 000

0 0.5 1 2 3 4 Km