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Magnetic Susceptibility as a Tool of Lithological Mapping: A Case Study from Malekhu-Damauli Area of Central Nepal, Lesser Himalaya

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Abstract
Magnetic susceptibility (MS) along different roads, foot-trails and river sections has been measured in rock outcrops. The measured major sections are Malekhu-Dhading road, Mugling-Jugedi road, Ghumaune-Damauli road, Mugling-Anbu Khaireni-Badinpur road, Shivapur- Gwaslung road, Malekhu Khola section, Trishuli and Seti river sections and other small tributaries near road sections. A pocket susceptibility meter (ZH Instruments SM30) was used to measure MS values of rocks which belong to the Nawakot Group, Bhimphedi Group and the Tanahun Group. For the values of MS in the study area, site mean MS (average of 10 to15 readings at each outcrop) data gave the following variations: (i) a large range of average MS between (-0.0097 - 387) x 10^{-3} SI; (ii) lowest MS magnitudes (<0.1 x 10^{-3} SI) for quartzite, limestone, dolomite, which are predominantly composed of diamagnetic minerals (e.g. quartz, calcite and dolomite); (iii) intermediate range of (0.1-1.0 x 10^{-3} SI) was found in most shales, slates, phyllites, sandstones and schists; and (iv) high values (>1.0 x 10^{-3} SI) for amphibolites, green-schists, meta-sandstones, and iron rich beds. The range of unique values of MS could be used for lithological mapping and hence the stratigraphic as well as structural interpretations.

Key words: magnetic minerals, Nawakot group, stratigraphic correlation, Tanahun group

Introduction
The magnetic susceptibility (MS) is the indicator of the concentration of magnetic minerals in the rocks and minerals. The detailed properties of the rocks should be known for effective planning and execution of engineering geological works. The MS is a physical parameter which is used to characterize and differentiate the rocks that are widely used in mineral and oil exploration for assessment of quality and quantity of materials in land, water and air system in natural media or even for assessment of the degree of pollution or contamination by pollutants or heavy metals due to anthropological activities (Gautam *et al.* 2011). The unique set of MS values can be used in the geological as well as lithological mapping (Hrouda *et al*. 2009).

There are many problems of correlation of the Lesser Himalayan rocks in central Nepal. Due to the lack of fossil contents, biostratigraphy is not possible everywhere; so total correlation is based on the lithostratigraphy. Dating based correlation is also poor in the absence of laboratory facilities in Nepal. Mostly rock types found in the area are slate, phyllite, meta-sandstone, quartzite, limestone and dolomite almost in all geological units but in varying proportions. Similar type of lithology is found in many units as separated out by marker beds, for example, there is pelitic, crenulated and soapy phyllite in the Kunchha Formation, Dandagaon Phyllite, Nourpul Formation and Robang Formation. Similar type of situation is found in the quartzite and carbonate rocks. For example, mappable succession of quartzite is seen in the Kunchha Formation, Fagfog Quartzite, Nourpul Formation and the Robang Formation. Due to the absence of other evidences except lithological similarity, geological mapping and naming the rock units has no uniformities (Stöcklin & Bhattarai 1977,

and Paudyal & Paudel 2011, 2014) (Fig. 1 and Fig. 2). Figure 1 showed the stratigraphy by Stöcklin & Bhattarai (1977) where they have shown several members within the Kunchha Formation. Later, Paudyal & Paudel (2011, 2014) have re-mapped the same area in 1:25,000. (Fig.2). According to them, the oldest member of the Kunchha Formation, the Anpu Quartzite is equivalent to the Fagfog Quartzite. Similarly, the Labdi Khola Member of the Kunchha Formation is equivalent to the Dandagaon Phyllite and the Banspani Quartzite member of the Kunchha Formation is equivalent to the Purebensi Quartzite of the Nourpul Formation. This brought a great change in strarigraphy and hence, in tectonic interpretations. Such type of difficulties exists in the name and stratigraphic position in other parts of the Lesser Himalaya. As we know the Lesser Himalaya is a fold-and thrust belt. Due to thrusting similar type of lithology of two different units may come in contact to each other. However, during mapping we may interpret it in our convenience. It has made a great confusion in the mapping and structural interpretations. Present study has aimed to delineate this macroscopically similar succession from the different units based on the unique values of the MS. The MS measurement was carried out in the Malekhu section, Mugling-Jugedi section, Mugling-Anpu Khaireni-Bandipur section, Pohari-Arkhala section as well as Kahun Shivpur section. In Malekhu section, there is good exposure of both the Nawakot Group and the Bhimphedi Group and this section is considered a type section for the central part of the Lesser Himalaya. An attempt was made to correlate these rocks with the similar type of rocks westward from Malekhu. Rocks exposed in the Mugling-Jugedi and its adjacent areas is lithologically similar to that of the Nawakot Group and the rocks in Kahun area (Tanahun Group) can be correlated with the rocks of the Bhimphedi Group.

However, there are no other bases of correlation except lithological similarity on the stratigraphic succession. Therefore, measurement of MS has been used as another tool to correlate the succession in different part of the Lesser Himalaya.

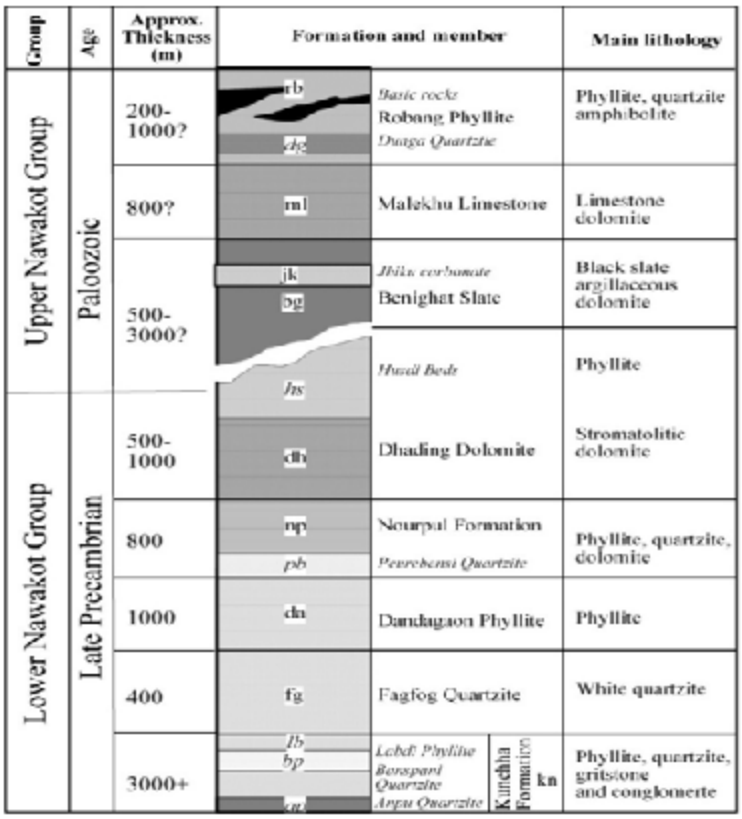

Fig. 1. Lithostratigraphy of the Nawakot complex proposed by Stöcklin and Bhattarai (1977) and Stöcklin (1980)

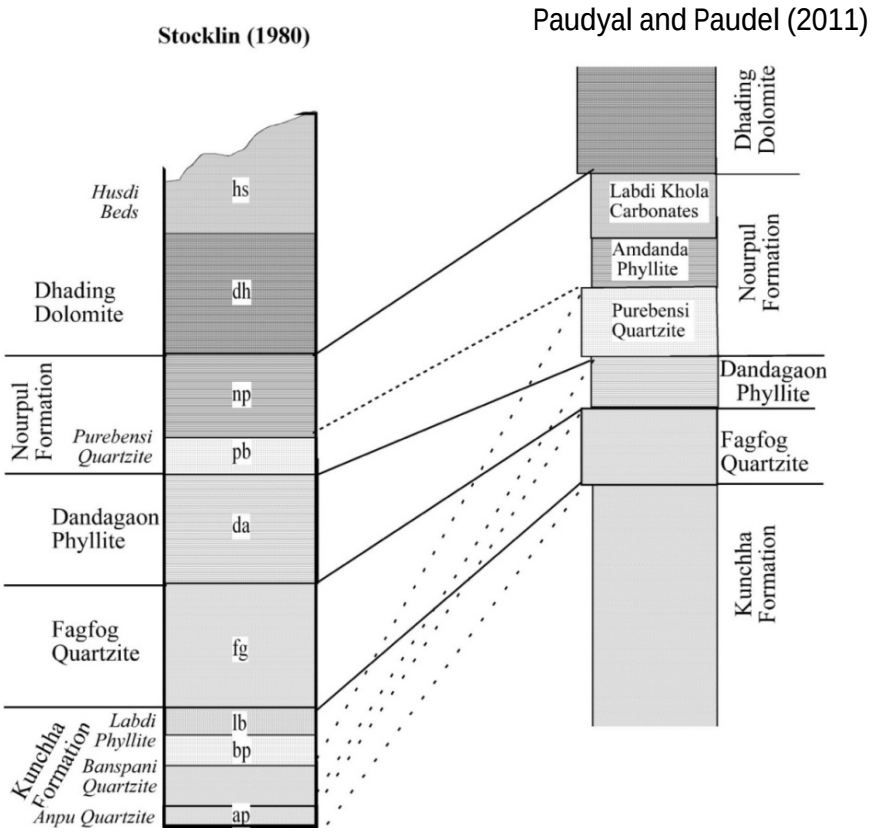

Fig. 2. Comparison of the revised lithostratigraphy of the Mugling-Banspani area by Paudyal and Paudyal (2011) with that of Stöcklin and Bhattarai (1977) and Stöcklin (1980) in Malekhu area

Methodology

Field measurements of in situ MS were made on the major roads- Malekhu-Dhading road, Mugling-Jugedi road, Ghumaune-Damauli road, Mugling-Anbu Khaireni-Badinpur road, Shivapur- Gwaslung road, Malekhu Khola section, Trishuli and Seti River sections and other small tributaries near road sections using a SM 30 (ZH Instruments, Czech Republic) hand-held/pocket magnetic susceptibility meter (Fig.3.). For the measurement of the MS values, exposure of rocks especially the fresh and smooth surfaces were selected as far as possible to which the susceptibility sensor could be attached to close as possible at each site. At least 10 to 15 spot readings were taken on rock surfaces of similar type of lithology distributed over an area of several metre square. Also GPS readings were taken at the each site. Four character indexes have been assigned for each measurement (e.g. DhDl, Dh=Dhading Dolomite, Dl=Dolomite, NpSs; Np = Nourpul Formation, Ss= sandstone and so on).The data processing involved calculation of simple statistical parameters using MS excel worksheet: min, max, average and standard deviation.

Results and Discussion

Malekhu section

The MS of each rock type in Lesser Himalayan rocks of the Nawakot Group and the rocks of the Bhimphedi Group (except Markhu Formation was measured systematically in the field (Table 1). In total, 32 sites were selected covering all the units. The main rock types of the Nawakot Group include phyllite, metasandstone, quartzite, slate, dolomite etc. The value of MS is varied from -0.005 - 28.843 in these rocks. The Fagfog Quartzite has relatively the lowest MS value (ranges from -0.005 - 0.0815) than other units. High MS value (1.654) was found in the schist of the Kulekhani Formation. Anomalously high MS value (3.063-28.843) was obtained in the succession of the Chisapani Quartzite (Table 1).

Table 1. In MS data derived from measurements at rocky outcrops along Malekhu section

Site	Latitude deg N	Longitude deg E	Mean	Stdv	Min	Max	Formation	Lithological index
MS32(ii)	27.46'718	27.46'718	1.6547	0.399284	0.987	2.2	Kulekhani	KuSc
MS32(i)	27.46'718	27.46'718	0.629083	0.456708	0.126	1.68	Kulekhani	KuQt
MS31	27.46'743	27.46'743	0.14	0.014772	0.123	0.159	Chisapani	ChAg
MS30	27.46'829	27.46'829	0.6215	0.177648	0.139	1.67	Chisapani	ChQt
MS29(iii)	27.46'851	27.46'851	3.063	1.248413	1.22	5.81	Chisapani	ChSc
MS29(ii)	27.46'851	27.46'851	28.843	20.68958	8.02	80.2	Chisapani	ChQt
MS29(i)	27.46'851	27.46'851	0.25875	0.118351	0.173	0.429	Chisapani	ChQt
MS28	27.47'403	27.47'403	0.199357	0.042197	0.147	0.27	Kalitar	KtSc
MS27	27.47'502	27.47'502	0.6215	0.177648	0.339	0.806	Kalitar	KtSc
MS26	27.47'549	27.47'549	0.055775	0.024868	0.0237	0.104	Bhainsedobhan	BhMb
MS25	27.47'667	27.47'667	0.0905	0.179717	0.0143	0.063	Bhainsedobhan	BhMb
MS24	27.47'846	27.47'846	0.191	0.036415	0.21	0.299	Raduwa	RaSc
MS23	27.47'992	27.47'992	-0.00663	0.011875	-0.0244	0.0084	Robang	DuQt
MS22	27.47'991	27.47'991	0.02459	0.026025	0.0063	0.0957	Robang	DuQt
MS21	27.48'068	27.48'068	0.5286	0.063174	0.431	0.622	Robang	RbAm
MS20	27.48'161	27.48'161	0.2757	0.027897	0.218	0.327	Robang	RbPh
MS19	27.48'182	27.48'182	0.0408	0.030289	0.0034	0.0825	Robang	RbQt
MS18	27.48'313	27.48'313	0.086691	0.028492	0.0583	0.16	Malekhu	MlDl
MS17	7.48379	27.48379	0.10138	0.020596	0.0717	0.114	Malekhu	MlDl
MS16	7.48632	27.48632	0.070933	0.032769	0.0112	0.122	Malekhu	MlDl
MS15	7.4865	27.4865	0.166467	0.025486	0.123	0.2	Benighat	BeSl
MS14	7.48741	27.48741	0.085093	0.022444	0.0638	0.144	Benighat	BeSl
MS13S	7.49681	27.49681	0.02487	0.021206	0.004	0.077	Dhading	DhDl
MS12	7.49732	27.49732	0.02855	0.033483	0.0006	0.0877	Nourpul	NpDl
MS11	7.49808	27.49808	0.0635	0.059672	0.0003	0.151	Nourpul	NpQt
MS10(iii)	7.50056	27.50056	0.082914	0.025508	0.0558	0.129	Nourpul	NpSst
MS10(ii)	7.50056	27.50056	0.3039	0.038587	0.242	0.363	Nourpul	NpSh
MS10(i)	7.50056	27.50056	0.119386	0.036242	0.0764	0.176	Nourpul	NpSh
MS9	7.50457	27.50457	0.03265	0.018592	0.0107	0.0707	Purebesi	PbQt
MS8	7.50604	27.50604	0.026821	0.012437	0.0104	0.0503	Purebesi	PbQt
MS7	7.50916	27.50916	0.163213	0.055315	0.0775	0.286	Dandagaon	DnPh
MS6	7.50988	27.50988	0.00305	0.004384	-0.005	0.0104	Fagfog	FgQt
MS5	7.51025	27.51025	0.08151	0.068513	0.0202	0.0634	Fagfog	FgPh
MS4	7.51102	27.51102	0.011107	0.013274	-0.0082	0.0526	Fagfog	FgQt
MS3	7.51808	27.51808	0.331818	0.100733	0.225	0.5	Kunchha	KnPh
MS2	7.51854	27.51854	0.262	0.096731	0.13	0.48	Kunchha	KnPh
MS1(iii)	7.51942	27.51942	0.137311	0.063223	0.0146	0.231	Kunchha	Knmst
MS1(ii)	7.51942	27.51942	0.3185	0.063716	0.192	0.399	Kunchha	KnPh
MS1(i)	7.51942	27.51942	0.173067	0.07262	0.094	0.295	Kunchha	KnPh

Note: Statistics is based on 15 or more measurements on smooth surfaces randomly distributed at each outcrop. In the index given in the last column, the first two characters indicate Formation/Member name: Kn: Kunchha; Fg:Fagfog; Dn:Dandagaon; Pb;Purebesi; Np:Nourpul; Dh:Dhading; Be:Benighat; Ml:Malekhu; Rb:Robang; Du:Dunga; Ra:Raduwa; Bd:Bhainsedobhn; Kt:Kalitar; Ch:Chisapani; Ku:Kulekhani and the following two characters stand for predominant rock type (Ph:phyllite; Dl: dolomite; Qt:quartzite Sh:shale; Sc:schist; Am:Amphibolite; Sl:slate; Mb:marble; Ag:augengneiss; mst: metasandstone.

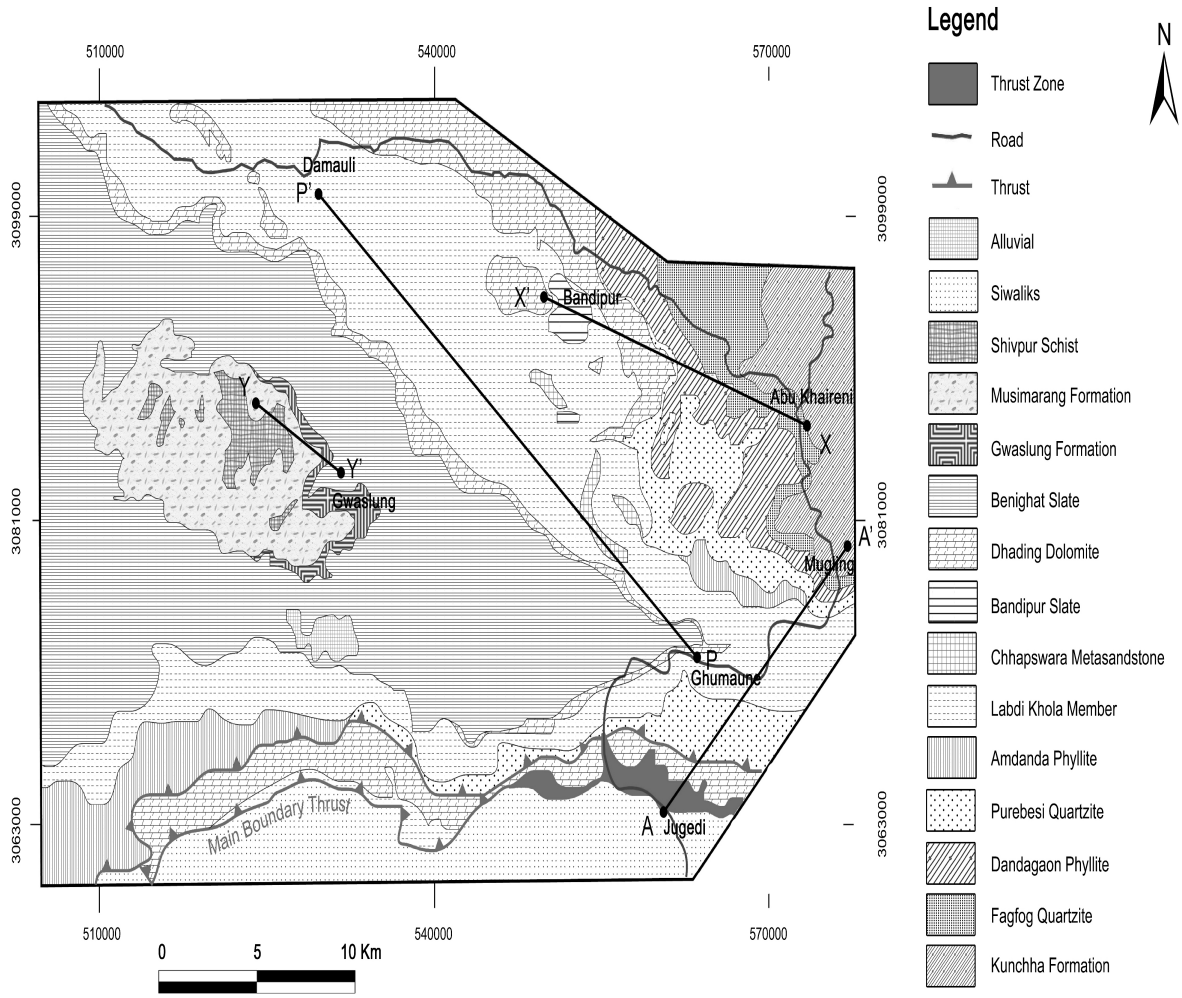

Fig.3. Location of suveyed routes in geological map (Paudyal and Paudel, 2014) of the area

Muglin-Jugedi section

About 26 km long Mugling-Jugedi road section was selected for the MS measurement of the rocks exposed in this area. Altogether 24 sites were selected for the measurement of MS representing each litho-type from each unit. The MS values varied for different rock types of the individual formations. It has varied from (-0.0069- 41.14) (Table 2). The Fagfog Quartzite has the least MS value (-0.0069- 0.0054) whereas amphibolites/metabasic rocks of the Nourpul Formation showed high to very high MS values (1.91-41.14). Anomalous MS value (=23.24) was obtained from the gritty phyllite of the Kunchha Formation along this route.

Ghumaune-Damauli Section

About 20 km long earthern road section was selected for the MS measurements. The rocks of the Nawakot Group are exposed in the area (P-P') section (Fig.3). In total, 15 sites were selected for the MS measurement representing all litho-type of each formation. The rocks of the study area are represented by quartzite, shale, sandstone and dolomite. T h e MS values varied at different formations and it also varied within the same formation too (Table 3). The MS value varied from 0.002 for (quartzite of the Labdi Khola Member) to 387 for hematite of the Labdi Khola Member.

Table 2. In situ MS data derived from measurements at rocky outcrops along Muglin-Jugedi section

Site	Lattitude degN	Longitude degE	Mean	Stdx	Min	Max	Formation	Lithological Index
MS56	27.46’757	84.26’664	0.148329	0.040266	0.0793	0.191	Siwalik(M)	Sisst
MS54(ii)	27.47'876	84.26'032	0.022333	0.007401	0.0158	0.0298	Benighat	BeSl
MS52	27.49'128	84.26'761	0.1548	0.025486	0.119	0.205	Benighat	BeSl
MS51(ii)	27.49'146	84.27'426	0.018191	0.011663	-0.0116	0.294	Dhading	DhDl
MS55	27.47'758	84.26'021	-0.00549	0.003583	-0.0087	0.0008	Dhading	DhDl
MS54(i)	27.47'876	84.26'032	-0.00014	0.006255	-0.0081	0.01	Dhading	DhDl
MS53(i)	27.48'049	84.26'041	0.067017	0.042273	0.0401	0.149	Purebesi	PbQt
MS51(i)	27.49'146	84.27'426	0.054229	0.036977	0.0041	0.101	Dhading	DhDl
MS53(iii)	27.48'049	84.26'041	0.438111	0.208108	0.146	0.766	Nourpul	NpPh
MS53(ii)	27.48'049	84.26'041	41.14444	13.92992	10.38	57.9	Nourpul	NpAm
MS50	27.49'117	84.27'422	0.0697	0.02496	0.0279	0.113	Nourpul	NpDl
MS49	27.49'300	84.28'156	0.10423	0.028831	0.0805	0.151	Nourpul	Npmst
MS48	27.49'301	84.28'150	1.914167	0.369187	1.2	2.39	Nourpul	Npmst
MS47(iii)	27.49'405	84.28'136	0.13873	0.070214	0.0787	0.3	Nourpul	Npmst
MS47(ii)	27.49'405	84.28'136	0.416125	0.231387	0.165	0.906	Nourpul	Npmst
MS47(i)	27.49'405	84.28'136	38.77778	19.01043	3.39	73.2	Nourpul	NpAm
MS46(ii)	---	----	0.215273	0.031445	0.151	0.251	Nourpul	NpSh
MS46(i)	----	-----	0.078933	0.024642	0.0503	0.129	Nourpul	NpDl
MS45	27.49'348	84.31'428	0.04917	0.027741	0.0115	0.0889	Nourpul	NpDl
MS44	27.49'462	84.31'422	0.150143	0.022741	0.121	0.194	Nourpul	NpSh
MS43(iii)	27.50'357	84.33'583	0.6947	0.093671	0.597	0.906	Nourpul	NpAm
MS43(ii)	27.50'357	84.33'583	0.7646	0.084565	0.701	0.902	Nourpul	NpPh
MS43(i)	27.50'357	84.33'583	0.02415	0.02109	0.01	0.0301	Nourpul	PbQt
MS42	27.50'572	84.33643	0.093117	0.103741	0.0121	0.397	Nourpul	PbQt
MS41	27.50'572	84.33643	0.2779	0.044583	0.2	0.354	Dandagaon	DnPh
MS40	27.50'573	84.33'583	0.231667	0.046148	0.141	0.303	Dandagaon	DnPh
MS39	27.50'658	84.33'636	-0.00696	0.005489	-0.0179	0.0016	Fagfog	FgQt
MS38	27.50'770	84.33'670	0.005475	0.010752	-0.0056	0.0279	Fagfog	FgQt
MS37	27.50'818	84.33'685	23.24667	11.07724	6.92	41.6	Kunchha	Knph
MS36(ii)	27.50'861	84.33'667	0.2512	0.043476	0.168	0.337	Kunchha	KnPh
MS36(i)	27.50'861	84.33'667	0.113044	0.038575	0.0813	0.192	Kunchha	Knmst
MS35	27.50'942	84.33'674	0.14627	0.03787	0.0947	0.209	Kunchha	KnPh
MS34(ii)	27.50'040	84.33'648	0.2942	0.097896	0.202	0.4	Kunchha	KnPh
MS34(i)	27.50'040	84.33'648	0.13835	0.0478	0.0825	0.196	Kunchha	Knmst
MS33	27.51'226	84.33'631	0.0973	0.047203	0.0631	0.228	Kunchha	Knmst

Note: Statistics is based on 15 or more measurements on smooth surfaces randomly distributed at each outcrop. In the index given in the last column, the first two characters indicate Formation/Member name: Kn:Kunchha;Fg:Fagfog; Dn:Dandagaon; Pb;Purebesi; Np:Nourpul; Dh:Dhading; Be: Benighat; si:siwalik and the following two characters stand for predominant rock type (Ph:phyllite; Dl: dolomite; Qt:quartzite; Sh: shale; Sc:schist; Sl: slate; Am:Amphibolite; mst: metasandstone

Table 3. In situ MS data derived from measurements at rocky outcrops along Ghumaune-Damauli section

Site	Latitude deg N	Longitude deg E	Mean	Stdv	Min	Max	Formation	Lithological index
MS65(i)			0.07709	0.033149	0.045	0.162	Benighat	BeSl
MS61	27.50'835	84.25'184	0.1929	0.050043	0.122	0.269	Benighat	BeSl
MS60	27.49'564	84.28'181	0.055118	0.019046	0.033	0.097	Benighat	BeSl
MS59	27.49'456	84.27'973	0.1935	0.016359	0.162	0.216	Benighat	BeSl
MS58(ii)	27.49'423	84.27'989	0.022318	0.014391	0.0026	0.0467	Dhading	DhDl
MS68	27.55'852	84.17'054	0.010573	0.020292	-0.0039	0.0694	Dhading	DhDl
MS62	----	------	0.02652	0.021269	0.0048	0.0706	Dhading	DhDl
MS65(ii)	-----	-------	0.013587	0.008949	-0.0042	0.027	Dhading	DhDl
MS71	27.56'582	84.16'596	0.06445	0.089728	0.015	0.0712	Nourpul	NpSl
MS70	27.56'936	84.16'769	0.1818	0.040732	0.131	0.238	Nourpul	NpPh
MS69(ii)	27.57'752	84.16'793	0.2749	0.04851	0.22	0.365	Nourpul	NpPh
MS69(i)	27.57'752	84.16'793	0.036227	0.022456	0.0093	0.0909	Nourpul	Npmst
MS67(ii)	------	------	0.6618	0.130423	0.471	0.917	Nourpul	NpAm
MS67(i)	------	-------	0.00205	0.005809	-0.0098	0.011	Nourpul	NpQt
MS66	27.50'648	84.26'526	0.01729	0.011787	0.0054	0.0412	Nourpul	NpQt
MS64	------	-------	387	199.8725	162	544	Nourpul	NpFe
MS63	27.50'043	84.28'097	0.3002	0.055023	0.197	0.355	Nourpul	NpPh
MS58(i)	27.49'423	84.27'989	0.08139	0.046535	0.016	0.174	Nourpul	NpDl
MS57	27.49'399	84.28'033	0.10618	0.03972	0.0179	0.147	Nourpul	NpDl

Note: Statistics is based on 15 or more measurements on smooth surfaces randomly distributed at each outcrop. In the index given in the last column, the first two characters indicate Formation/Member name Np:Nourpul; Dh:Dhading; Be:Benighat; and the following two characters stand for predominant rock type (Ph:phyllite; Dl: dolomite; Qt:quartzite; Sl: slate; Fe:Iron content; Am:Amphibolite; and mst:metasandstone

Mugling-Bandipur section

The rocks exposed in this section were mapped under the Kunchha Formation, Fagfog Quartzite, Dandagaon Phyllite, and the Nourpul Formation with the Bandipur Slate (member) and the Dhading Dolomite from bottom to top respectively. Altogether 9 sites were selected for the measurement of the MS values (x-x', Fig.3). Major rock types are represented by phyllite, dolomite, slate and metasandstone. In this section, the MS values ranged from -0.0097 (low) -0.306 (intermediate) even from the rocks of the same Nourpul Formation (Table 4).

Table 4. In situ MS data derived from measurements at rocky outcrops along Mugling-Bandipur section

Site	Latitude deg N	Longitude deg E	Mean	stdv	Min	Max	Formation	Lithological index index
MS83	27.56'275	84.24'261	0.019458	0.019867	-0.0025	0.0652	Dhading	DhDl
MS85	27.56'113	84.24'321	0.018318	0.010325	0.003	0.0446	Dhading	DhDl
MS86	27.57'527	84.25'005	0.011655	0.007314	-0.0047	0.0255	Dhading	DhDl
MS84(i)	27.56'163	84.24'689	0.306717	0.299931	0.048	0.969	Nourpul	NpMst
MS84(ii)	27.56'163	84.24'689	0.217083	0.030467	0.155	0.26	Bandipur Slate	BaSl
MS88	27.54'633	84.30'236	-0.00971	0.01168	-0.0251	0.0125	Nourpul	NpQt
MS87(i)	27.54'664	84.30'262	0.161636	0.105922	0.1	0.476	Dandagaon	DnPh
MS87(ii)	27.54'664	84.30'263	0.1776	0.030607	0.142	0.211	Dandagaon	DnMst
MS91	27.53'440	84.32'524	0.0051	0.0051	0.0216	0.007	Fagfog	FgQt
MS89	27.54'197	84.32'704	0.11664	0.035183	0.0557	0.0.174	Kunchha	Knmst
MS90	27.54'156	84.32'733	0.1686	0.030113	0.126	0.21	Kunchha	KnPh

Note: Statistics is based on 15 or more measurements on smooth surfaces randomly distributed at each outcrop. In the index given in the last column, the first two characters indicate Formation/Membername Kn:Kunchha; Fg:Fagfog; Dn:Dandagaon; Np:Nourpul; Dh:Dhading; Ba:Bandipur; and the following two characters stand for predominant rock type (Ph:phyllite; Dl: dolomite; Qt:quartzite; Sh: shale; Sl: slate; mst: metasandstone

Shivapur-Gwaslung section

Metamorphic crystalline rocks of the Kahun Klippe (Tanahun Group) are found in this section. The rocks of the crystalline succession were divided into three formations as the Gwaslung Formation, the Musimaran Formation and the Shivpur Schist from bottom to top respectively (Fig.4). Altogether 11 sites were selected to represent all types of rocks of the area represented by marble, quartzite, garnet-schist and two-mica-schist. The marble of the Gwaslung Formation has obtained relatively low MS value (=0.0078) whereas the two-micaceous-schist of the Musimarang Formation has intermediate (= 0.229) value (Table 4).

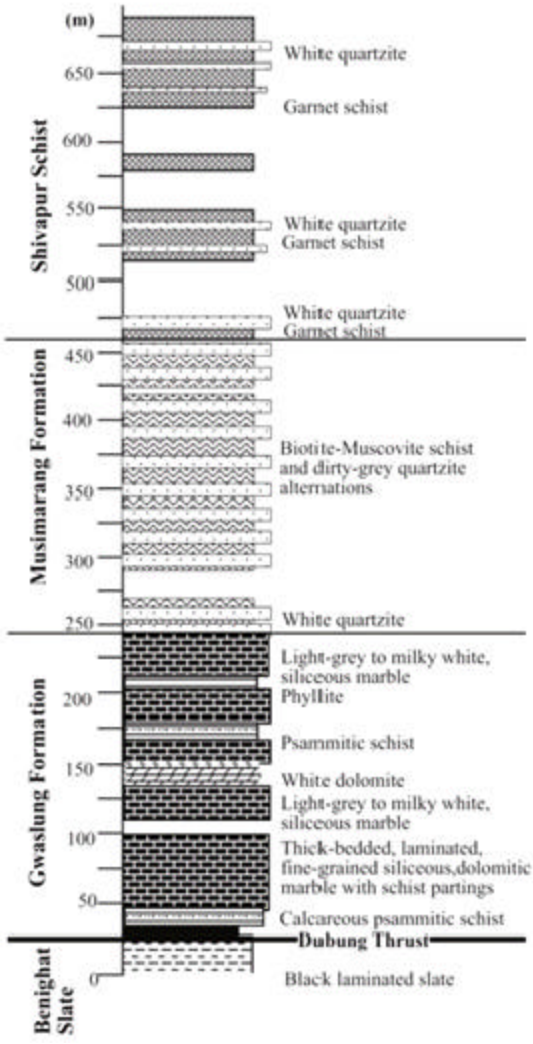

Fig .4. Generalized columnar section of rocks of the Tanahun Group at Gwaslung-Shivpur area

The MS values were different for different types of rocks depending on the concentration of the dia, para and ferro-magnetic minerals. They were higher in basic rocks and iron-bearing formations as compared to sedimentary and metamorphic rocks composed of rock forming silicates in the region. In the present study, the meta-basic rocks (e.g. amphibolites) showed moderate to high values. Some sedimentary and metamorphic rocks may contain higher values due to the presence of magnetic minerals (e.g. metasandstone of the Nourpul Formation along the Mugling-Jugedi section, MS-48, Table 2.0). Low MS values were found in rocks composed of silica (e.g. quartzite), carbonates (e.g. dolomite), carbon (e.g. graphitic slate), silica and feldspar (e.g. metasandstone). Some rocks showed anomalous values, for example, some bands of quartzite and schist of the Chisapani Quartzite, gritty phyllite of the Kunchha Formation and hematite containing meta-sedimentary formation of Labdi Khola Member (Labdi Khola Carbonate in Fig.2) showed anomalously high MS values. The reason of higher MS values could be explained in terms of high abundance of ferromagnetic minerals or ore body of the iron or ferrugineous srocks. Based on the MS values obtained from the present study, the rocks of the region could be categorized into four ranges as low, moderate, high and very high. Such categorization is important while using MS to statistically discriminate the Lesser Himalayan lithostratigraphic units from each other (Gautam *et al*. 2010). The importance of the MS range could be considered for the comparision of the rocks exposed in different but same tectonic environment. The MS values of the Raduwa Formation of the Bhimphedi Group are correlable to the rocks of the Shivpur Schist of the Tanahun Group. However, the MS values of the other formations of this groups were not correlable. This might be one basis to correlate the uppermost unit i.e. the Shivpur Schist with that of the Raduwa Formation. On that basis too, the other units older than the Shivpur Schist were possibly the older units than the Raduwa Formation in central Nepal. The Mahabharat Thrust might cut relatively at the shallower depth in central Nepal (Paudyal & Paudel 2013).

In certain cases, the MS values of different rocks of different formations might yield similar values. In such cases, MS values should be looked for the total succession. For example, pelitic phyllites of the Kunchha Formation and the Dandagaon Phyllite have

similar MS values. The same case arised in the MS values of the white quartzites of the Fagfog Quartzite and the Dunga Quartzite. These data showed that MS values could be used as mapping tools for a total succession, but not always to separable into minor formations. There are several international and national geo-scientists involved in the lithological as well as geological mapping of the Lesser Himalaya in central Nepal (e.g. Stöcklin & Bhattarai 1977, Stöcklin 1980, Sakai 1985, Hirayama *et al*. 1988, Dhital *et al*. 1987, 2002, Jnawali & Tuladhar 1996, 1999, Sah 2007, Paudyal & Paudel 2011, 2013, 2014, Rai 2011) for the sake of geological investigations. However, the published literature revealed that mapping was not uniform in terms of the similar lithologies to the various formations, often with different names. Macroscopically, similar rock assemblage may not be included in the similar stratigraphic unit in mapping. For example, the Fagfog Quartzite could be differentiated with the Purebensi Quartzite of the Nuwakot Group on the basis of stratigraphical position. When these two rocks come in contact due to faults or thrusts, the boundary may not be differentiated; rather both can be included within the same formation.

Table 5. In situ MS data derived from measurements at rocky outcrops along Shivapur-Gwaslung section

Site	Latitude	Longitude	Mean	Stdv	Min	Max	Formation	Lithological Index
	deg N	deg E						
MS82	27.54'854	84.16'595	0.04159	0.010549	0.0182	0.0551	Benighat	Besl
MS81(ii)	27.54'231	84.16'402	0.08034	0.022367	0.0581	0.111	Benighat	BeMsi
MS81(i)	27.54'231	84.16'402	0.15873	0.042574	0.0933	0.23	Benighat	Besl
MS80	27.54'066	84.16'078	0.13685	0.076796	0.0321	0.282	Thrust	ThSl
MS73	27.53'868	84.15'222	0.183267	0.041694	0.135	0.288	Shivapur	ShSc
MS72	27.53'800	84.14'496	0.17892	0.210414	0.0725	0.927	Musimarang	MnSc
MS74(i)	27.53'906	84.15'241	0.0106	0.012316	-0.004	0.023	Musimarang	MnQt
MS74(ii)	27.53'906	84.15'241	0.051743	0.037888	0.0069	0.094	Musimarang	MnPh
MS76(i)	27.54'175	84.15'524	0.024558	0.021906	0.0043	0.0898	Musimarang	MnQt
MS76(ii)	27.54'175	84.15'524	0.2291	0.100215	0.132	0.499	Musimarang	MnSc
MS75	27.53'835	84.16'425	0.00769	0.009026	-0.005	0.026	Gwaslung	GwMb
MS77	27.54'169	84.15'780	0.04167	0.015629	0.0235	0.0675	Gwaslung	GwMb
MS78	27.54'179	84.15'844	0.02307	0.004371	0.0179	0.0332	Gwaslung	GwQt
MS79	27.54'217	84.15'887	0.0078	0.010484	-0.0011	0.0097	Gwaslung	GwMb

Note: Statistics is based on 15 or more measurements on smooth surfaces randomly distributed at each outcrop. In the index given in the last column, the first two characters indicate formation/member name Mn:Musimaran; Sh:Shivapur; Gw:Gwaslung and Be:Benighat; and the following two characters stand for predominant rock type :Ph:phyllite; Qt:quartzite; Sh: shale; Sc:schist; Sl: slate; and Mb:Marble

Conclusion

The study areas represented the rock succession of the Nawakot Group, Bhimphedi Group and Tanahun Group (rocks of the Kahun Klippe). Measurements of MS of these rocks were carried out through six representative routes. The rocks of the Nawakot Group of the Malekhu section were correlable with the rocks exposed in the Mugling-Damauli sections and its adjacent area based on the MS values. There was well correlation of these meta-sedimentary rocks if they were viewed in the total succession. The least value was obtained from the silicates, carbonates and graphite/carbonaceous rich rocks like quartzites, dolomites and graphitic slates. Moderate MS values were found in the pelitic rocks like shale, slate, phyllites and schists; some meta-sandstones; amphibolites and some meta-basites. Similarly, higher MS values were obtained from gritty phyllite of the Kunchha Formaiton, meta-basic rocks of the Nourpul Formation, metasandstones and iron formations of the Labdi Khola Member (member of the Nourpul Formation). The variation of MS values could be justified on the basis of concentration of dia, para and ferro-magnetic minerals present in the rocks. Di-magnetic minerals possessed negative value, para-magnetic showed low values while the ferromagnetic minerals had high MS values. Some macroscopically identical units could also be differentiated on the basis of MS values, for example, the rocks of the Fagfog Quartzite (MS= - 0.006 - 0.005) could be distinguished with the rocks of the Purebensi

Quartzite (MS=0.026 - 0.093) as both consist of monotonous succession of quartzite. Similarly, the pelitic rocks (phyllites/slates) of the Kunchha Formation (MS=0.173 - 0.318) and the Dandagaon Phyllite (0.163 - 0.231) can be distinguished with the graphitic slate of the Benighat Slate (0.020 - 0.085) on the basis of MS values. These unique values were useful for the distinction of typical or specified lithology and hence for the lithological mapping. The MS values of the Raduwa Formation of the Bhimphedi Group were correlable to the rocks of the Shivpur Schist of the Tanahun Group, however; the MS values of the other formations of these groups were not correlable.

MS measurement was found useful to locate the magnetic ore bodies or iron formations based on their high MS values. Anomalously high values of the quartzite and schist of the Chisapani Quartzite were found suddenly in certain bands. Similarly, the Labdi Khola iron deposit also showed exceptionally high values and at the spot of ore body MS meter stopped its measurement.

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