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We prove Poincaré-Sobolev and related inequalities for rectifiable varifolds in $\mathbf{R}^N$. In particular, all our results apply to properly immersed submanifolds of $\mathbf{R}^N$.

Suppose $M \subset B_R = B_R(0) \subset \mathbf{R}^N = \mathbf{R}^{n+k}$ for some $R > 0$, and $V = v(M, \theta)$ is a countably n-rectifiable varifold in B_R with generalised mean curvature vector H. μ is the weight measure defined by $\mu = \theta H^n \lfloor M$. $h\colon M \to R$ is a Lipschitz function.

In Theorem 1 we prove a Poincaré-Sobolev result for non-negative h in case $\mu\{\xi\colon h(\xi) > 0\} < \omega_n R^n$ and $h \in W^{1,p}(\mu)$ for some $p < n$. This generalises a Poincaré result of Leon Simon; but in addition the relevant constant here does not depend on $\mu(B_R)$. Theorem 2 is an Orlicz space result in case $p = n$.

The proofs of Theorems 1 and 2 use a covering argument to obtain weak L^p type estimates on $\mu\{\xi\colon h(\xi) > s\}$.

Theorems 3 and 4 are generalisations of Theorems 1 and 2 in case there is no restriction on $\mu\{\xi\colon h(\xi) \neq 0\}$ (again the constants in the estimates do not depend on $\mu(B_R)$). The conclusion of Theorem 4 is analogous to the conclusion of the John-Nirenberg theorem for functions of bounded mean oscillation.

We prove Poincaré-Sobolev and related inequalities for rectifiable varifolds in $\mathbf{R}^N$. In particular, all our results apply to properly immersed submanifolds of $\mathbf{R}^N$.

Theorem 1 is a refinement of a result due to Leon Simon. In [Sc; p. 70] and [S; Theorem 18.4, p. 91] one has a similar Poincaré inequality in case $p = 1$ and $|H|$ is bounded, but with a constant c depending on $\mathbf{M}(V\lfloor B_R)$. In Theorem 1, c depends only on p and the dimension of V. This is important in case we have no a priori density bound for V at 0 (as in [H], which provided the motivation for the present paper).

We also remark that the Poincaré result in Theorem 1 for $p > 1$ does not seem to follow directly from the case $p = 1$—the usual trick of replacing h by h^r does not work since the integrals in the inequality occur over balls of different radius. Nonetheless, one can use the Sobolev inequality for functions *with* compact support and a cut-off function argument to "bootstrap" up from the $p = 1$ case. However, the proof in Theorem 1 gives the Poincaré result directly for all p and with the constant dependence as noted above. The Sobolev result then follows immediately (as pointed out by Leon Simon) by a simple cut-off function argument from the result in the compact support case (this latter was first established in [**A**; Theorem 7.3] and [**MS**]).

In Theorem 2 we prove an Orlicz space result in case $h \in W^{1,n}(\mu)$, where n is the dimension of V and μ is the measure in $\mathbf{R}^N$ induced by V.

The proofs of Theorems 1 and 2 use a covering argument to obtain weak L^p type estimates on $\mu\{\xi\colon h(\xi) > s\}$, and were motivated in part by the proof of the Sobolev inequality for functions with compact support in [**S**; Theorem 18.6, p. 93].

Theorems 3 and 4 are generalisations of Theorems 1 and 2 in case there is no restriction on $\mu\{\xi\colon h(\xi) \neq 0\}$ (again the constants in the estimates do not depend on $\mathbf{M}(V\lfloor B_R)$). They follow directly from Theorems 1 and 2, as was also realised by Leon Simon in the context of his Poincaré inequality discussed previously [private communication]. The conclusion of Theorem 4 is analogous to the conclusion of the John-Nirenberg theorem for functions of bounded mean oscillation.

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NOTATION. Throughout this paper we use the notations and conventions of [**S**].

In each of the following theorems we take the following hypotheses:

(H): *$M \subset B_R = B_R(0) \subset \mathbf{R}^N = \mathbf{R}^{n+k}$ for some $R > 0$, and $V = \mathbf{v}(M, \theta)$ is a countably n-rectifiable varifold in B_R with generalised mean curvature vector H. μ is the weight measure defined by $\mu = \theta H^n\lfloor M$. $h\colon M \to \mathbf{R}$ is a Lipschitz function.*

Convention. All integrals are taken with respect to μ, unless otherwise clear from context.

THEOREM 1. *Suppose* **(H)**. *Suppose also that $h(\xi) \geq 0$ for all $\xi \in M$ and that $\mu\{\xi\colon h(\xi) > 0\} \leq \omega_n R^n(1 - \alpha)$ for some $\alpha > 0$.*

Then there are constants $c = c(n, p)$ *and* $\beta = \beta(n, \alpha) > 0$ *such that*

$$\left[\int_{B_{\beta R}} h^{np/(n-p)}\right]^{(n-p)/np} \le \frac{c}{\alpha}\left[\int_{B_R} h^p|H|^p + |\nabla^M h|^p\right]^{1/p}$$

whenever $1 \le p < n$.

Remarks. (1) The hypothesis $\mu\{\xi\colon h(\xi) > 0\} \le \omega_n R^n(1-\alpha)$ for some $\alpha > 0$ is clearly necessary, as one sees by letting $V = \mathbf{v}(M, 1)$ where M consists of two n-dimensional affine spaces passing through the origin, and setting $h = 1, 2$ respectively on the two spaces.

The necessity of taking the left integral in the theorem over $B_{\beta R}$, rather than over B_R, is clear if one considers a modification of the above example in which one of the affine spaces is displaced slightly from the origin.

(2) From Hölder's inequality one obtains under the same assumptions that

$$\left[\int_{B_{\beta R}} h^q\right]^{1/q} \le cR^{1+n/q-n/p}\left[\int_{B_R} h^p|H|^p + |\nabla^M h|^p\right]^{1/p}$$

in case $1 \le p < n$ and $1 \le q \le np/(n-p)$, or in case $p \ge n$ and $1 \le q < \infty$. In the first case $c = c(n, p)$ and in the second case $c = c(n, q)$.

Proof of Theorem. Our main goal is to prove the estimate (11). Without loss of generality assume $R = 1$.

Fix $s > 0$ and define

$$f(\xi) = \min\{h(\xi), s\}. \tag{1}$$

In the following suppose

$$0 < \beta < 1/2. \tag{2}$$

We will later further restrict β.

Applying the monotonicity formula to f^p, we have for each $\xi \in B_\beta$ that

$$\frac{\partial}{\partial\rho}\left[\rho^{-n}\int_{B_\rho(\xi)} f^p\right] \ge -\rho^{-n}\int_{B_\rho(\xi)}[f^p|H| + |\nabla^M f^p|], \tag{3}$$

(in the distributional sense in r) provided $0 < \rho < 1-\beta$. (See [S;

18.1, p. 89], where this result is stated for C^1 functions. The extension to the Lipschitz case follows by first extending f to a Lipschitz function $\underline{f}$ on $\mathbf{R}^{n+k}$, then mollifying in $\mathbf{R}^{n+k}$, recalling that up to a set of H^n measure zero M is a disjoint union of sets M_i, each of which is a subset of a C^1 manifold N_i, and finally showing that for each i the *integrals* on each side of (3) (over $M_i \cap B_\rho(\xi)$ instead of $M \cap B_\rho(\xi)$) are the limit of corresponding integrals with f replaced by the mollified function $\underline{f}_\varepsilon$. This last step makes essential use of the fact that ∇^M is a *tangential* derivative.)

For μ a.e. ξ with $|\xi| < \beta$ and $h(\xi) \geq s$, we see from (2) that

$$
\begin{aligned}
(4)\qquad s^p = f^p(\xi) &\leq \sup_{0<\sigma<1-\beta} \omega_n^{-1}\sigma^{-n}\int_{B_\sigma(\xi)} f^p \\
&\leq \omega_n^{-1}(1-\beta)^{-n}\int_{B_{1-\beta}(\xi)} f^p \\
&\quad + c\int_0^{1-\beta}\tau^{-n}\int_{B_\tau(\xi)}[f^p|H| + |\nabla^M f^p|] \\
&\leq \omega_n^{-1}(1-\beta)^{-n}\omega_n(1-\alpha)s^p \\
&\quad + c\int_0^{1-\beta}\tau^{-n}\int_{B_\tau(\xi)}[f^p|H| + |\nabla^M f^p|] \\
&\leq (1-\alpha/2)s^p + c\int_0^{1-\beta}\tau^{-n}\int_{B_\tau(\xi)}[f^p|H| + |\nabla^M f^p|],
\end{aligned}
$$

for suitable $\beta = \beta(n, \alpha)$, which we now fix.

It follows

$$
\begin{aligned}
&\sup_{0<\sigma<1-\beta} \omega_n^{-1}\sigma^{-n}\int_{B_\sigma(\xi)} f^p \\
&\quad\leq \frac{c}{\alpha}\int_0^{1-\beta}\tau^{-n}\int_{B_\tau(\xi)}[f^p|H| + |\nabla^M f^p|] \\
&\quad\leq \frac{c}{\alpha}\int_0^{1-\beta}\tau^{-n}\int_{B_\tau(\xi)} f^{p-1}[f|H| + |\nabla^M f|] \\
&\quad\leq \frac{c}{\alpha}\left[\sup_{0<\sigma<1-\beta}\sigma^{-n}\int_{B_\sigma(\xi)} f^p\right]^{1-1/p} \\
&\qquad\times\int_0^{1-\beta}\left[\tau^{-n}\int_{B_\tau(\xi)} f^p|H|^p + |\nabla^M f|^p\right]^{1/p}.
\end{aligned}
$$

Thus for any $0 < \sigma < 1 - \beta$,

$$\begin{aligned}
(5)\quad &\left[\sup_{0<\sigma<1-\beta} \omega_n^{-1}\sigma^{-n}\int_{B_\sigma(\xi)} f^p\right]^{1/p} \\
&\leq \frac{c}{\alpha}\int_0^{1-\beta}\left[\tau^{-n}\int_{B_\tau(\xi)} f^p|H|^p + |\nabla^M f|^p\right]^{1/p} \\
&\leq \frac{c}{\alpha}\int_0^{\rho_0}\left[\tau^{-n}\int_{B_\tau(\xi)} f^p|H|^p + |\nabla^M f|^p\right]^{1/p} \\
&\quad + \frac{c}{\alpha}\int_{\rho_0}^{1-\beta}\left[\tau^{-n}\int_{B_\tau(\xi)} f^p|H|^p + |\nabla^M f|^p\right]^{1/p} \\
&\leq \frac{c}{\alpha}\int_0^{\rho_0}\left[\tau^{-n}\int_{B_\tau(\xi)} f^p|H|^p + |\nabla^M f|^p\right]^{1/p} + \frac{c_1\Gamma}{\alpha}\rho_0^{1-n/p},
\end{aligned}$$

where we set

$$(6)\qquad \Gamma = \left[\int_{B_1(0)} f^p|H|^p + |\nabla^M f|^p\right]^{1/p}.$$

Now choose s_0 so that

$$(7)\qquad \frac{c_1\Gamma}{\alpha}\left(\frac{1}{10}\right)^{1-n/p} = \frac{1}{2}s_0.$$

For each $s \geq s_0$ choose $\rho_0 = \rho_0(s)$ such that

$$(8)\qquad \frac{c_1\Gamma}{\alpha}(\rho_0^{1-n/p}) = \frac{1}{2}s,$$

i.e.

$$(9)\qquad \rho_0 = c_2\left(\frac{\Gamma}{\alpha s}\right)^{p/(n-p)}.$$

Note that

$$(10)\qquad \rho_0 \leq \frac{1}{10}.$$

From (5), (8), (10), (2), (4) we have for $s \geq s_0$ and ρ_0 as in (9), that

$$\begin{aligned}
&\left[\sup_{0<\sigma<1-\beta} \omega_n^{-1}\sigma^{-n}\int_{B_\sigma(\xi)} f^p\right]^{1/p} \\
&\leq \frac{c}{\alpha}\int_0^{\rho_0}\left[\tau^{-n}\int_{B_\tau(\xi)} f^p|H|^p + |\nabla^M f|^p\right]^{1/p}.
\end{aligned}$$

Hence

$$\left[\sup_{0<\sigma<(1-\beta)/5} \sigma^{-n}\int_{B_{5\sigma}(\xi)} f^p\right]^{1/p} \le \frac{c}{\alpha}\rho_0\left[\tau^{-n}\int_{B_\tau(\xi)} f^p|H|^p + \nabla^M f|^p\right]^{1/p}$$

for some $0<\tau=\tau(\xi)<\rho_0$.

Since $\rho_0 \le 1/10 < (1-\beta)/5$ from (10) and (2), it follows from (9) that for this particular $\tau=\tau(\xi)<\rho_0$ we have

$$\int_{B_{5\tau}(\xi)} f^p \le \frac{c}{\alpha^p}\rho_0^p \int_{B_\tau(\xi)} f^p|H|^p + |\nabla^M f|^p,$$

where ρ_0 is as in (9).

Since this is true for μ a.e. $\xi\in B_\beta\cap\{h\ge s\}$, it follows from (10), (2) and a standard covering argument (see [S: Theorem 3.3, p. 11]) that

$$\int_{B_\beta\cap\{h\ge s\}} f^p \le \frac{c}{\alpha^p}\rho_0^p\int_{B_1} f^p|H|^p + |\nabla^M f|^p,$$

and so for any $s\ge s_0$ we have (using (9)) that

$$\mu(B_\beta\cap\{h\ge s\}) \le c\left(\frac{\Gamma\rho_0}{\alpha s}\right)^p \le c\left(\frac{\Gamma}{\alpha s}\right)^{np/(n-p)}. \tag{11}$$

(Since $\mu(B_\rho\cap\{h>0\})<\omega_n$, this last inequality is true for *all* $s>0$.)

It follows from (11) and the fact $\mu(B_\beta\cap\{h\ge 0\})\le\omega_n$ that

$$\begin{aligned}\int_{B_\beta} h^p &= p\int_0^\infty s^{p-1}\mu(B_\beta\cap\{h\ge s\}) \\ &= p\int_0^{\Gamma/\alpha} s^{p-1}\mu(B_\beta\cap\{h\ge s\}) \\ &\quad + p\int_{\Gamma/\alpha}^\infty s^{p-1}\mu(B_\beta\cap\{h\ge s\}) \\ &\le c\left(\frac{\Gamma}{\alpha}\right)^p + c\int_{\Gamma/\alpha}^\infty s^{p-1}\left(\frac{\Gamma}{\alpha s}\right)^{np/(n-p)} \\ &\le c\left(\frac{\Gamma}{\alpha}\right)^p + c\left(\frac{\Gamma}{\alpha}\right)^p\int_1^\infty t^{p-1}t^{-np/(n-p)}\,dt \le c\left(\frac{\Gamma}{\alpha}\right)^p.\end{aligned} \tag{12}$$

(*Remarks.* One can similarly estimate the integral of h^q for any $1\le q<np/(n-p)$.)

Finally suppose $\varphi\in C_c^\infty(B_1)$, $0\le\varphi\le1$, $\varphi\equiv1$ on $B_{\beta/2}$, $\varphi\equiv0$ on $B_1\sim B_\beta$, and $|D\varphi|\le c/\beta$. From the appropriate Sobolev inequality for functions with compact support (for example, see [S; Theorem 18.6, p. 93], replace h there with h^r where $r = p(n-1)/(n-p)$, and use Hölder's inequality) it follows

$$\begin{aligned}\left[\int_{B_1} (\varphi h)^{np/(n-p)}\right]^{(n-p)/n} &\le c\int_{B_1} \varphi^p h^p |H|^p + |\nabla^M(\varphi h)|^p \\ &\le \frac{c}{\alpha^p}\left[\int_{B_1} h^p|H|^p + |\nabla^M h|^p\right],\end{aligned}$$

using (12). Hence

$$\left[\int_{B_{\beta/2}} h^{np/(n-p)}\right]^{(n-p)/np} \le \frac{c}{\alpha}\left[\int_{B_1} h^p|H|^p + |\nabla^M h|^p\right]^{1/p}.$$

This establishes the theorem. □

THEOREM 2. *Under the same hypotheses as Theorem* 1, *there exist* $\beta = \beta(n) > 0$, $\gamma_1 = \gamma_1(n) > 0$, *and* $\gamma_2 = \gamma_2(n)$, *such that*

$$\int_{B_{\beta R}} \left(\frac{\alpha h}{\Gamma}\right)^n \exp\left(\frac{\gamma_1 \alpha h}{\Gamma}\right) \le \gamma_2 R^n,$$

where

$$\Gamma = \left[\int_{B_R} h^n|H|^n + |\nabla^M h|^n\right]^{1/n}.$$

Proof. Choosing $R = 1$ and arguing exactly as in the proof of Theorem 1, with $p = n$, we obtain instead of (5) that

$$(5)' \qquad \begin{aligned}&\left[\sup_{0<\sigma<1-\beta} \omega_n^{-1}\sigma^{-n}\int_{B_\sigma(\xi)} f^n\right]^{1/n} \\ &\quad\le \frac{c}{\alpha}\int_0^{\rho_0}\left[\tau^{-n}\int_{B_\tau(\xi)} f^n|H|^n + |\nabla^M f|^n\right]^{1/n} \\ &\quad\quad + \frac{\bar{c}_1\Gamma}{\alpha}\log(\rho_0^{-1}).\end{aligned}$$

Choose s_0 so that

$$(7)' \qquad \frac{\bar{c}_1\Gamma}{\alpha}\log\left(\frac{1}{10}\right)^{-1} = \frac{1}{2}s_0.$$

For each $s \ge s_0$ choose $\rho_0 = \rho_0(s)$ such that

$$(8)' \qquad \frac{\bar{c}_1\Gamma}{\alpha}\log\rho_0^{-1} = \frac{1}{2}s,$$

i.e.

$$(9)' \qquad \rho_0 = \exp\left(-\frac{\bar{c}_2 \alpha s}{\Gamma}\right).$$

Arguing again exactly as before, we obtain for any $s \geq s_0$ that

$$(11)' \qquad \mu(B_\rho \cap \{h \geq s\}) \leq c\left(\frac{\Gamma \rho_0}{\alpha s}\right)^n \leq c\left(\frac{\Gamma}{\alpha s}\right)^n \exp\left(-\frac{c_3 \alpha s}{\Gamma}\right).$$

(This is then true for any $s > 0$ since $\mu(B_\beta \cap \{h \geq 0\}) < \omega_n$.)

By Fubini's theorem we see that if $\varphi(s)$ is a C^1 increasing function of s for $s \geq 0$, and $\varphi(0) = 0$, then (since $h \geq 0$ on $B_\beta \cap M$)

$$\int_{B_\beta} \varphi(u) = \int_0^\infty \varphi'(s) \mu(B_\beta \cap \{h \geq s\})\, ds.$$

If we let

$$\varphi(s) = \left(\frac{\alpha s}{\Gamma}\right)^n \exp\left(\frac{\gamma_1 \alpha s}{\Gamma}\right),$$

where γ_1 is yet to be chosen, it follows from $(11)'$ and the fact $\mu(B_\beta \cap \{h \geq s\}) < \omega_n$ that

$$\begin{aligned}
&\int_{B_\beta} \left(\frac{\alpha h}{\Gamma}\right)^n \exp\left(\frac{\gamma_1 \alpha h}{\Gamma}\right) \\
&\quad \leq \omega_n \int_0^{\Gamma/\alpha} \left[\frac{\alpha}{\Gamma}\left(\frac{\alpha s}{\Gamma}\right)^{n-1} + \gamma_1 \left(\frac{\alpha s}{\Gamma}\right)^n\right] \exp\left(\frac{\gamma_1 \alpha s}{\Gamma}\right) \\
&\qquad + c \int_{T/\alpha}^\infty \left[\frac{\alpha}{\Gamma}\left(\frac{\alpha s}{\Gamma}\right)^{n-1} + \gamma_1 \frac{\alpha}{\Gamma}\left(\frac{\alpha s}{\Gamma}\right)^n\right] \\
&\qquad \times \exp\left(\frac{\gamma_1 \alpha s}{\Gamma}\right)\left(\frac{\Gamma}{\alpha s}\right)^n \exp\left(-\frac{c_3 \alpha s}{\Gamma}\right) \\
&\quad \leq \gamma_2, \quad \text{say},
\end{aligned}$$

where we choose $\gamma_1 = c_3/2$. □

Theorem 3. *Suppose* **(H)**. *Suppose* $\alpha > 0$ *and choose* N *such that* $\mu(M) \leq N\omega_n(1 - \alpha)$.

Choose any $\lambda_1 < \cdots < \lambda_M$ *such that*

$$\begin{aligned}
\mu\{h < \lambda_1\} &\leq \omega_n - \alpha, \\
\mu\{\lambda_i < h < \lambda_{i+1}\} &\leq \omega_n - \alpha \qquad \textit{for } i = 1, \ldots, N, \\
\mu\{\lambda_M < h\} &\leq \omega_n - \alpha.
\end{aligned}$$

This is clearly possible for some $M \leq N - 1$.

Then if $1 \leq p < n$ *and* $p \leq q \leq np/(n-p)$, *there exist constants* $c = c(n, p)$ *and* $\beta = \beta(n, \alpha)$ *such that*

$$\left[\int_{B_{\beta R}} \left(\inf_i |h - \lambda_i|\right)^q\right]^{1/q} \leq \frac{c}{\alpha} R^{1+n/q-n/p} \left[\int_{B_R} \left[\left(\inf_i |h - \lambda_i|\right)^p |H|^p + |\nabla^M h|^p\right]\right]^{1/p}.$$

The same result holds if $p \geq n$ *and* $p \leq q < \infty$, *but with* $c = c(n, q)$.

Remark. The necessity of allowing distinct values for the λ_i is clear if one considers examples where $V = \mathbf{v}(M, 1)$, M consists of distinct affine spaces, and h takes a distinct constant value on each affine space.

Proof of Theorem. Let

$$\begin{aligned} I_0 &= (-\infty, \lambda_1], \\ I_1 &= [\lambda_i, \lambda_{i+1}] \qquad i = 1, \dots, M-1, \\ I_M &= [\lambda_M, \infty). \end{aligned}$$

Define

$$h_j(\xi) = \begin{cases} \inf_i |h(\xi) - \lambda_i|, & h(\xi) \in I_j, \\ 0, & h(\xi) \notin I_j. \end{cases}$$

Let

$$\underline{h}(\xi) = \inf_i |h(\xi) - \lambda_i| = \sum_j h_j(\xi).$$

Then for each $\xi \in M$ there exists at most one j such that $h_j(\xi) \neq 0$. Moreover, each $h_j(\xi)$ is Lipschitz. Finally, for H^n a.e. $\xi \in M \cap \{h \in I_j\}$ we have $\nabla^M h_j(\xi) = \nabla^M h(\xi)$, and so $\nabla^M \underline{h}(\xi) = \nabla^M h(\xi)$ for H^n a.e. $\xi \in M$.

Taking β as in Theorem 1, it follows that

$$\left[\int_{B_{\beta R}} \underline{h}^q\right]^{p/q} = \left[\int_{B_{\beta R}} \left(\sum_j h_j^p\right)^{q/p}\right]^{p/q} \leq \sum_j \left[\int_{B_{\beta R}} (h_j^p)^{q/p}\right]^{p/q}$$

(by Minkowski's inequality, using $q \geq p$)

$$\leq \sum_j \frac{c}{\alpha^p} R^{p+(np/q)-n} \left[\int_{B_R} h_j^p |H|^p + |\nabla^M h_j|^p \right]$$

(by Theorem 1 and the remark following it)

$$= \frac{c}{\alpha^p} R^{p+(np/q)-n} \left[\int_{B_R} \underline{h}^p |H|^p + |\nabla^M h|^p \right].$$

Remark. The restriction $q \geq p$ is required in order that the constant c not depend on $\mu(B_R)$.

Theorem 4. *Suppose the same hypotheses hold as in the previous theorem.*

Then there exist $\beta = \beta(n) > 0$, $\gamma_1 = \gamma_1(n) > 0$, *and* $\gamma_2 = \gamma_2(n)$, *such that*

$$\int_{B_{\beta R}} \left(\frac{\alpha \underline{h}}{\underline{\Gamma}} \right)^n \exp\left(\frac{\gamma_1 \alpha \underline{h}}{\underline{\Gamma}} \right) d\mu \leq \gamma_2 R^n,$$

where

$$\underline{h}(\xi) = \inf_i |h(\xi) - \lambda_i|,$$

$$\underline{\Gamma} = \left[\int_{B_R} \underline{h}^n |H|^n + |\nabla^M h|^n \right]^{1/n}.$$

Proof. Define λ_i and h_j as in the proof of the previous theorem. Then

$$\int_{B_{\beta R}} (\alpha h_j)^n \exp\left(\frac{\gamma_1 \alpha h_j}{\Gamma_j} \right) \leq \gamma_2 \Gamma_j^n,$$

where β, γ_1 and γ_2 are as in Theorem 2, and where

$$\Gamma_j = \left[\int_{B_R} h_j^n |H|^n + |\nabla^M h_j|^n \right]^{1/n}.$$

Replacing Γ_j by $\underline{\Gamma}$ on the left side (as $\Gamma_j \leq \underline{\Gamma}$), and then summing the inequality over j, we obtain the required result. □

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